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Final Report

The Goddard High Resolution Spectrograph Scientific Support Contract

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December 13, 1993 – December 12, 1996

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Contents

List of Acronyms

AAS	American Astronomical Society
COSTAR	Corrective Optics Space Telescope Axial Replacement
DAF	Data Analysis Facility
FGS	Fine Guidance Sensor
FOS	Faint Object Spectrograph
GHRS	Goddard High Resolution Spectrograph
GSFC	Goddard Space Flight Center
GTO	Guaranteed Time Observation
HST	Hubble Space Telescope
IDL	Interactive Data Language
IDT	Investigation Definition Team
IUE	International Ultraviolet Explorer
LASP	Laboratory for Astronomy and Solar Physics
LSA	Large Science Aperture
MAMA	Multi-Anode Microchannel Plate Array
NICMOS	Near-Infrared Camera Multi-Object Spectrograph
SSA	Small Science Aperture
SSC	Science Support Center or Contract
SMOV	Servicing Mission Observatory Verification
STIS	Space Telescope Imaging Spectrograph
STScI	Space Telescope Science Institute
WFPC	Wide Field Planetary Camera

Introduction

In 1988, Computer Sciences Corporation (CSC) was selected as the Goddard High Resolution Spectrograph (GHRS) Scientific Support Contractor (SSC). This was to have been a few months before the launch of NASA's first Great Observatory, the *Hubble Space Telescope (HST*. As one of five scientific instruments on *HST*, the GHRS was designed to obtain spectra in the 1050–3300 Å ultraviolet wavelength region with a resolving power, $\lambda/\Delta\lambda$, of up to 100,000 and relative photometric accuracy to 1%. It was built built by Ball AeroSpace Systems Group under the guidance of the GHRS Investigation Definition Team (IDT), comprised of 16 scientists from the US and Canada. After launch, the IDT was to perform the initial instrument calibration and execute a broad scientific program during a five-year Guaranteed Time Observation (GTO) period.

After a year's delay, the launch of *HST* occurred in April 1990, and CSC participated in the in-orbit calibration and first four years of GTO observations with the IDT. This was a time of exceptional challenges for the team, and some frustrations. While eagerly exploiting new opportunities opened by the GHRS, team members were disappointed with what seemed to be an endless string of impediments to the science program. The *HST* primary mirror suffered from spherical aberration, which reduced the spatial and spectral resolution of Large Science Aperture (LSA) observations and decreased the throughput of the Small Science Aperture (SSA) by a factor of two. Periodic problems with the Side 1 carrousel electronics and anomalies with the low-voltage power supply finally resulted in a suspension of the use of Side 1 less than two years after launch. And although there was an expectation that in-orbit operations would be immature at the beginning of the mission, inefficiencies in the ground system and errors in implementing the team's science program often slashed the available time on-target for many objects in the GTO program.

Much of this was to change with the *HST* first servicing mission in December 1993. The Corrective Optics Space Telescope Axial Replacement (COSTAR) unit was to correct spherical aberration at the instrument focal plane, albeit with the addition of two optical reflections that effectively eliminated observations from 1050–1150 Å. The GHRS Redundancy Kit, to be bolted to the GHRS structure and cabled between the *HST* and GHRS electronics, provided a direct interface to the Side 2 electronics, enabling the resumption of Side 1 operations without fear of losing Side 2 communications.

It was in this context that the follow-on contract for the GHRS SSC was awarded to CSC. This report summarizes the accomplishments of that work, covering the period from December 13, 1993, during the *HST* first servicing mission, to December, 12, 1996, two months before the removal of the GHRS from *HST* in second servicing mission.

The GHRS SSC had two principal functions. First, it was to supply science support for the entire IDT, such as archiving *HST* data at a central repository at GSFC and providing data analysis assistance with the team's data reduction software, developed by Advanced Computer Concepts, Inc. (ACC). Secondly, it was to provide research associates to assist the co-investigators at GSFC in carrying out their individual GTO programs. To broaden the foundation for these functions, CSC developed an integrated operations and research organization, where staff members assumed multiple duties and responsibilities, contributing assistance wherever needed by the team. This philosophy proved itself time and again as new problems, and opportunities, unfolded.

At the outset, the GHRS SSC tasks involved work in four areas:

- To manage and operate the GHRS Data Analysis Facility (DAF)
- To support the second Servicing Mission Observatory Verification (SMOV) program, as well as perform system engineering analyses of the GHRS as necessary
- To assist the GHRS IDT with their scientific research programs, particularly the GSFC members of the team
- To provide administrative and logistical support for GHRS public information and educational activities

As time progressed, further tasks were added for other GSFC/LASP projects. For the infrared group, CSC provided library research and data base entry support for the Catalog of Infrared Observations, under by D. Gezari. For the astronomy branch, CSC used its GHRS, *IUE*, and STScI experience for Space Telescope Imaging Spectrograph (STIS) science operations development, parallel observation planning, and prelaunch calibrations, under the lead of the Principal Investigator, B. Woodgate. Finally, CSC researchers collaborated with GSFC scientists on a wide-range of *HST* Guest Observer programs and observing proposals with other satellites and ground-based telescopes, expanding the pioneering work done in the LASP with the GHRS.

CSC staff members for the GHRS SSC during this reporting period are listed in Table 1 under their major areas of activity.

Table 1. GHRS Scientific Support Contractor Staff

<u>GHRS Science Team</u>

Dr. Vladimir S. Airapetian	Ms. Mona R. Drexler
Dr. Thomas B. Ake	Dr. Eliot M. Malumuth
Mr. James H. Blackwell	Dr. Charles R. Proffitt
Ms. Ruth E. Bradley	Dr. Richard D. Robinson
Dr. Tomas E. Brage	Ms. Jennifer L. Sandoval
Dr. Frederick C. Bruhweiler	Dr. Glenn M. Wahlgren
Dr. D. Michael Crenshaw	

<u>STIS Operations Team</u>

Dr. Steven B. Kraemer	Dr. James W. Younger

<u>Infrared Data Base Group</u>

Ms. Patricia S. Pitts

Table 2 lists the GHRS GSFC co-investigators and the CSC research associates chiefly involved with their studies.

Table 2. GSFC GHRS Co-Investigators and CSC Research Associates

Dr. Albert Boggess Crenshaw, Bruhweiler	Dr. David S. Leckrone Brage, Proffitt, Wahlgren
Dr. Kenneth G. Carpenter Airapetian, Robinson	Dr. Stephen P. Maran Crenshaw, Robinson
Dr. Sara R. Heap, Co-PI Malumuth	Dr. Andrew M. Smith Bruhweiler

Other members of the GHRS IDT who were not located at GSFC are shown with their affiliations in Table 3.

Table 3. Off-Site GHRS Co-Investigators

Dr. Edward A. Beaver UCSD	Dr. Jeffrey L. Linsky U. Colorado
Dr. John. C. Brandt, PI U. Colorado	Dr. Blair D. Savage U. Wisconsin
Dr. Dennis C. Ebbets Ball AeroSpace	Dr. Lawrence M. Trafton U. Texas
Dr. John B. Hutchings DAO	Dr. Frederick M. Walter SUNY
Dr. Michael Jura UCLA	Dr. Ray J. Weymann OCIW

The following sections of this final report summarize the GHRS SSC activities in each subtask area. In some instances, the work represents a continuation of procedures and practices established during the first contract, which are not explained in detail here. As is usually the case, research projects in particular can entail several years of on-going studies and new work. Results presented here are those where the major part of the work was performed during the reporting period.

Summary of Activities

1 Project Support – Subtask 1

Project support for the GHRS IDT encompassed a variety of activities within the GTO program. These were mainly those functions that assisted all team members in scheduling and executing observing programs, interpreting in-orbit data, and disseminating scientific results. Close contact was maintained with the STScI to acquire up-to-date information on the performance of the GHRS after SMOV. The status of individual observing proposals for each IDT investigator was tracked, and the progress of the entire GTO program was monitored. Calibration and system engineering studies were performed as needed to provide independent analyses and recommendations to the team. With the advent of the World Wide Web, CSC initiated the development of a GHRS IDT home page. Lastly, administrative, logistical, and scientific support was provided for the GHRS Science Symposium, "The Scientific Impact of the Goddard High Resolution Spectrograph", held at GSFC in September 1996, which provided a summation of the major scientific contributions of the GHRS prior to its removal from the *HST*.

1.1 Proposal Preparation and Tracking

GTO proposals submitted by the IDT were tracked from submission through execution using a number of tools developed by SSC staff. Just prior to the first servicing mission, Malumuth and Ake updated their software that scanned flight Science Mission Specifications (SMSs) for GHRS and WFPC2 GTO parallel-field programs. They continued to distribute the products from these tools to the team. They summarized all GHRS observations and listed detailed time lines of activities, including identifying observation set names for each exposure. More detailed summary pages were also distributed to the Principal Investigator of each GTO program.

After development by the STScI of its PRESTO page on the WWW, Ake and Sandoval tracked and reported to the team the long-term scheduling status of GTO proposals. These reports were originally collated from the STScI long-range plan, but once the STScI no longer generated the plan, the PRESTO page for each proposal had to be examined to obtain information to monitor the progress of the entire GTO program. Ake and Sandoval distributed a biweekly status report listing the state of each proposal to the team. In number of cases, the SSC acted as the relay between team members and the STScI for scheduling questions and concerns.

The SSC staff provided assistance in the preparation and submission of *HST* GTO and GO proposals by team members for Cycles 4, 5, and 6. Ake helped compile GTO abstract and exposure catalogs required by the STScI to protect targets at the beginning of each proposal cycle. New versions of the Remote Proposal Submission System (RPSS) and its successor, RPS2, which schedules observations by orbits, were installed and tested as soon as they became available from the STScI. Task members were often the first users to test various features and reported failures or bugs back to the STScI.

Crenshaw, Blackwell, and Ake worked with K. Feggans (ACC) to write a tutorial for the team members on how to use RPS2 on the HRSSUN (Unix) computer.

1.2 SMOV and Post-COSTAR Calibration

CSC provided support to the GHRS IDT during the SMOV phase of the *HST* first servicing mission. The progress of the execution of SMOV observations was monitored through electronic mail, paper reports, and direct contact with GHRS personnel at the STScI. STARCAT was used to ensure that a complete set of data was obtained at GSFC for each proposal. Unlike the Science Verification period after the launch of *HST*, the GHRS IDT was not responsible for determining the in-orbit instrument calibration after the installation of COSTAR. However, SSC staff performed independent analyses for the team. Crenshaw assigned specific studies to SSC personnel for the analysis of dark counts, COSTAR mirror alignment, sensitivity, point- and line-spread functions, and other studies. Results from these studies were presented at the weekly local meetings and written as reports for inclusion in a new SMOV documentation data base. Printed versions of the SMOV reports were distributed to local team members, Ball Aerospace, and the STScI. A large display area was set up in the ground-floor hall of Building 21 to show the basic results from the studies. Regular meetings were held with GHRS personnel at the STScI to compare and discuss the results.

Malumuth analyzed the SMOV data from the coarse-focus alignment, fine-focus alignment, and x-tilt, y-tilt tests for the COSTAR M1 mirror alignment. The analysis technique involved examining each GHRS image, making surface plots, and integrating the light within circular apertures to construct encircled energy curves. He also determined the peak intensity in each image. These all were functions of the COSTAR M1 mirror-focus position and the x- and y-tilts. The best focus position was selected by the STScI to maximize the small-to-large science aperture throughput ratio. In working with G. Hartig (STScI), Malumuth found that COSTAR models predicted that the location of the stigmatic point lies between the apertures when this ratio is maximized, consistent with the image contours Malumuth generated.

Robinson used sequences of pre-COSTAR and post-COSTAR spectra taken with the same instrumental configurations and found a substantial decrease in the spectrograph sensitivity around 2000 Å. Studies of the relative throughput of the SSA compared with the LSA indicated an increase over the pre-COSTAR values, but not as much as expected. The throughput increased from around 47% near Lyman α to over 67% at 3000 Å, compared to pre-COSTAR measurements, which ranged from 25% to 35% over the same wavelength interval. Wahlgren and Robinson, working independently on analyzing data of μ Col, arrived at absolute sensitivity calibrations for the first-order gratings. The two analyses agreed almost exactly and showed a decreased sensitivity, relative to pre-COSTAR observations, for the wavelength range 1500 to 2500 Å, attaining a sensitivity low of 80% near 2000 Å. The sensitivity increased outside of this range for the rest of the wavelength region spanned by the first-order gratings.

Robinson derived several candidate point spread functions (PSFs), settling on two possibilities. However, neither of these was fully compatible with the data. The first agreed with all of the off-source observations, but had a very small amount of power in the wings. This PSF predicted a SSA/LSA intensity ratio of 82%, compared to the measured value of 54%. The other PSF had the correct power in the core, but too much power in the near wings, so that the observation offset by 0.2 arcsec was overpredicted by a factor of four. To see whether either of these PSFs were realistic, Robinson used them to construct line spread functions (LSFs), which were then tested using the data taken as part of SMOV proposal 4808. In this proposal, spectra of χ Lupi were taken at several wavelengths using the echelle and several first-order gratings. These data were obtained through both the LSA and the SSA. In the analysis, Robinson used the SSA echelle data as a "truth" spectrum. This spectrum was convolved with a derived LSF appropriate to the first-order gratings and the result compared with the first-order observations at that wavelength. The first-order SSA data was used to derive the instrumental profile, which was found to be a gaussian with FWHM of 0.165 arcsec.

Robinson worked to determine sensitivity and vignetting characteristics of the G160M, G200M, G270M, and G140L gratings. The sensitivities were derived using standard star fluxes which had been corrected by R. Bohlin (STScI) to the new *IUE* flux calibrations. Robinson also determined the blaze functions for both echelle A and B grating modes. The data used were part of the Cycle 4 calibration plan and consisted of spectra taken over the free spectral range for all of the orders for both sides. The data were analyzed by first running a CALHRS analysis for all spectra taken in a given order. This analysis applied a sensitivity and rough vignetting curve, but explicitly avoided the ripple correction. The individual spectra were then merged and a ratio was determined between the measured fluxes and reference fluxes obtained from a spectrophotometric atlas derived from first-order calibration data. This gave the raw blaze function. Final blaze functions were derived by fitting a theoretical curve through the observations. The curve was based on a single set of grating parameters for each echelle mode and several "fudge factors", which are needed to get the best fit. He found that a single set of correction factors was not sufficient to fit the observations, but that two pairs, one on either side of the echelle blaze maximum, would give a very good fit through the entire free spectral range of any given order. Robinson completed the final iterations to the sensitivity and vignetting calibration files for all of the first-order gratings. He also completed work on the sensitivity and blaze functions for both echelle modes, and the final versions of the echelle vignetting function.

Crenshaw, Sandoval, and Blackwell completed an analysis of detector background data from both GHRS detectors after the installation of COSTAR, and re-examined the entire set of dark count observations obtained since launch. Nearly all of the background in orbit was due to Cerenkov radiation induced in the digicon faceplates by cosmic rays. Outside of the SAA, the dark count rates exhibited the same behavior with geomagnetic latitude as before COSTAR, increasing by a factor of about two from 0 to 40 degrees. On average, the dark count rates remained constant over time, indicating that both the cosmic-ray environment and the sensitivities of the detectors to cosmic rays had not changed substantially since launch. A re-analysis of the dark count data in and around the SAA indicated that a significant fraction of observing programs could be continued inside of the GHRS contour then in effect, for as long as FGS guiding is enabled, without any substantial effect on the quality of the data. The results from this study were written up as a GHRS post-COSTAR calibration report and presented at a Telescope and Instrument Performance Summary (TIPS) meeting at the STScI.

1.3 In-Orbit Performance Papers

Ake, Robinson, and Wahlgren worked extensively on the team paper entitled "The Goddard High Resolution Spectrograph: In-Orbit Performance", which described the performance of the GHRS prior to the installation of COSTAR (Heap et al. 1995). They made extensive modifications and additions to the draft assembled by Heap, concentrating primarily on the wavelength calibration and spectral resolution, sensitivity functions, vignetting, echelle blaze function, scattered light, and fixed pattern noise. Robinson also generated a total of 25 figures for the paper. Ake and Robinson reviewed changes in subsequent drafts made by themselves and other authors. Ake submitted the paper to the PASP for the team and assisted Heap in editing the galley proofs. Blackwell created an Hypertext Markup Language (HTML) version of the paper for the GHRS IDT home page on the WWW.

Robinson completed a draft of a paper describing the post-COSTAR characteristics of the GHRS and started working with Ake on refining the manuscript. This will be the companion paper to the pre-COSTAR in-orbit performance paper. It summarizes changes to the GHRS point and line spread functions, throughput, and resolution due to the installation of COSTAR. A brief write-up of these results was converted to HTML format and placed on the WWW. This document contains links to figures that compare pre- and post-COSTAR characteristics of the GHRS.

1.4 Operations Studies

1.4.1 GHRS Efficiency

At the request of Brandt, in January 1994 Kraemer and Ake undertook a detailed study of a typical, week-long SMS to assess the efficiency of GHRS commanding and scheduling by the *HST* ground system. This was to be used to evaluate the degree of lost observing time to the GHRS GTO program. They chose the week of March 15, 1993 since it occurred after the last major change in GHRS operations, namely the "return-to-brightest" option for target acquisition, but prior to pointing restrictions imposed by the failure of the *HST* solar array drive electronics and magnetometer temperature limitations. Within this week, GHRS activities from proposals 3496, 2537, 1168, 1177, 3755, 3468, and 3608 were executed. Each activity was reviewed using the March 1993 Transformation Scripting Guide for input to timing calculations. The choice of activities scheduled within particular observing sequences was assessed.

Several problems in the commanding and scheduling were found. Deflection calibrations, which can take from two to ten minutes, were being scheduled during targeted times at the beginning of all onboard target acquisitions. A more efficient method would have been to perform the defcal as an internal during the time the target was occulted.

Moreover, all target acquisition activities were scheduled as their own separate alignments. Even activities that should be considered as part of the same target acquisition sequence, in particular the second half of the so-called "double locates", were forced into separate alignments. Activities, such as deflection calibrations, were being re-executed unnecessarily, since the same optical elements were being used and not enough time had elapsed to invalidate the previous calibration. In one observation examined in detail, 14% of the on-target time was wasted with unnecessary overheads.

In addition to the extra overhead time, unnecessary loading of new Observation Sequence Tables instead of Observation Control Tables increased the size of some command loads by approximately 50%. Improvements in commanding would have reduced the scheduling overheads and prevented the observer from having to add unnecessary revisits to a target because of reaching the command memory limit for a sequence of exposures.

There also seemed to be large amounts of alignment time scheduled beyond what was necessary to complete GHRS activities. When the STScI made the decision to drop ending spectrum Y-balances, to avoid leaving the calibration lamps on, they did not decrease the total alignment time. Ground system timing for the execution of GHRS substepping patterns required that the full pattern be completed. If a proposer requested an exposure time that did not allow for the full pattern completion, less than the full exposure time was used. However, the calculation of the alignment time used the exposure time from the proposer, not the the actual exposure time as executed. There appeared to be other problems with the alignment time calculations.

As a measure of the overall commanding and scheduling efficiency, calculations were made of the percentage of on-target time spent either doing internals or sitting idle after the completion of collecting photons. These were done in two ways, by averaging the inefficiency in the eleven GHRS obsets in this SMS, and secondly, by summing the total targeted time spent not accumulating target data during the week. The former method would give too much weight to exposure sequences of shorter duration. The percentages were 24% and 17%, respectively. These calculations did not include mechanism motions, relay configurations, or the management of data links, which are all non-photon collecting activities scheduled during targeted time, so the true fraction of wasted on-target time was greater.

1.4.2 GHRS Low-Noise Orbits

Ake initiated a study of how to reduce the GHRS background during an observation by scheduling exposures at the low-noise portions of *HST* orbits. Since the GHRS digicon detectors are effectively shielded from background radiation by the earth's magnetic field, observations at low geomagnetic latitudes have a lower dark-count rate. Using the model by Beaver characterizing the variation of background with geomagnetic latitude, Ake computed average backgrounds for observations occurring at different orbital positions. He tabulated the expected background vs. geographic longitude of the orbit ascending node. The average was found to range from 0.0045 to 0.0074 counts diode^{-1} s^{-1}. With the ascending node between 40 and 100 degrees east longitude, up to six contiguous orbits could be scheduled with an average background rate < 0.005 counts diode^{-1} s^{-1}.

These results were applied to the scheduling of Weymann's GTO 5172 proposal on the double quasar, Q0107–025AB. Ake worked with STScI personnel to schedule the appropriate orbits in September and November 1994. G140L spectra were obtained from 1200–1500 Å. After removal of O I λ1300 airglow lines, the background rates were found to be 0.0059 to 0.0067 counts diode^{-1} s^{-1}, about 25% higher than the model predicted.

1.5 Meetings and Information Distribution

One of most important functions of the GHRS SSC was to gather and distribute information to the IDT. At least one SSC member attended the weekly TIPS meetings at the STScI to gather the latest information on the performance of *HST* and its instruments, and to present the most recent information on the SSC's analyses. There were also frequent meetings between SSC members and the GHRS Instrument Scientists from the STScI concentrating specifically on GHRS issues. These meetings were particularly important during SMOV, when constant interaction was needed to understand the operation and calibration of the GHRS in conjunction with COSTAR.

SCC staff continued to participate in the semi-annual GHRS IDT meetings, which were held at GSFC or at AAS meetings. They presented results on proposal preparation, time allocation, calibration, public relations, and scientific results from GTO programs. Ake and Blackwell also attended Astronomical Data Analysis Software and Systems conferences to learn about and present results on operations, analysis software, and the use of the Internet and World Wide Web for gathering and distributing information. Ake, Malumuth, Robinson, and Sandoval attended the "Calibrating Hubble Space Telescope: Post Servicing Mission" workshop at the STScI and presented results on post-COSTAR data.

Frequent messages were distributed by e-mail to the IDT and their research assistants or associates concerning the status of *HST* and GHRS, STScI policies (including the allocation of GTO time), the first servicing mission SMOV, calibration results, software changes, notices of new data in GHRSLOG, and WFPC2 parallels news and observations. Most of these notices were also placed on the World Wide Web when the GHRS IDT home page was initiated. Questions from the team or associates that arose from the notices were answered by e-mail.

Hallway bulletin boards describing the status of GHRS and *HST* observations were maintained outside of the Data Analysis Facility (DAF) room. Items that were posted included: OPUS services reports, SMS activity summaries, GHRS commit reports, *HST* daily status reports, and press releases.

1.6 Public Information

Sandoval and Bradley retrieved *HST* press releases from the STScI over the WWW. Text and color images were downloaded and printed out. Photocopies were made, posted on bulletin boards, and distributed to interested local scientists. Color slides were obtained, placed in notebooks for general use, and distributed to interested team members.

Sandoval attended meetings of the AAS as a press officer assistant, helping out in the press room, putting together press kits, and providing general support to Maran. AAS posters made by local team members on GHRS results were posted in the halls in Building 21 at GSFC. Sandoval attended Space Astronomy Updates at NASA Headquarters at the request of Maran, and obtained copies of the press releases.

Sandoval worked on the new *HST* picturebook for Maran, which publicized the post-servicing mission results. She generated three images relating to Heap's Early Release Observation (ERO) of R136: the WFPC2 image of the field; the spectra of the two stars, R136A2 and R136A5; and a cartoon showing the probable evolution of a very massive star for both weak and strong mass-loss winds. She copied the images, saved as MacIntosh Superpaint PICT format files, via FTP to the STScI group that assembled the picturebook. She also quality-checked the beta version to make sure that the images were done properly.

1.7 The World Wide Web

Blackwell gave a presentation to the local team on the workings of the World Wide Web and how they might best prepare their work so that it will be readily usable on the GHRS WWW server. He covered the origin of the WWW, HTML basics, and the best methods for generating text and graphics that would be compatible with the requirements of the WWW. Ake and Crenshaw then worked on guidelines for the GHRS IDT home page. These included requirements for access and management of the page and summarized items to be installed, as suggested by the team. The WWW server was temporarily located on Blackwell's Macintosh pending the arrival of a permanent Unix-based server. The GHRS team received a new Sun computer (HRSSUN), and configured it with the necessary software to run the WWW server. After IDL was installed on the HRSSUN, Blackwell worked on ways to access IDL data bases from a Mosaic FORM-based page.

Robinson, Blackwell, and Ake completed a design document for the IDT home page. It grouped items into main categories, including information on the GHRS instrument, proposing and planning GHRS observing programs, GHRS observations and data bases, data reduction and calibration, scientific results, and using other *HST* instruments. A proposal preparation page included forms for computing GHRS spectral and target-acquisition count rates based on the team's IDL software. Access to the team's data archive, through a FORMS-based interface to the GHRSLOG data base and data retrieval forms, provided the capability to download any GHRS data that were non-proprietary. A "What's New" category included pointers to new items in the other main categories. HTML links to other sites that might be helpful and other useful documentation were also included. A description of each main category was placed under that category on the main page. Later on, main categories describing the GHRS Science Symposium and the GHRS archive on the WWW were added by Crenshaw. The home page can be found at `http://hrssun.gsfc.nasa.gov/ghrs-home-page.html`).

1.8 The GHRS Science Symposium

Planning for the GHRS Science Symposium "The Scientific Impact of the Goddard High Resolution Spectrograph" began in January 1996. A local organizing committee consisting of Ake, Crenshaw, and Robinson was formed to handle the logistics of the meeting, including plans for announcements, registration by e-mail and the WWW, accommodations, badges, parking, the location of the oral and poster sessions, and other details. Maran was added later as the committee chair to coordinate activities with other Goddard organizations. Ake, Brandt, and Maran met with S. Holt (GSFC) to obtain GSFC's backing for the symposium.

Robinson and Ake drafted the first announcement letter. It included the list of confirmed speakers, names of the organizing committee members, and a pre-registration form. To reach the largest audience, Ake assembled an e-mail distribution list for the initial mailing based on the Royal Greenwich Observatory Astropersons data base, to reach all North American astronomers, and the GHRS Space Telescope Analysis Newsletter distribution from the STScI, to include all GHRS users world-wide. However, he found that the Astropersons data base is very incomplete. Thus the *IUE* and *EUVE* Newsletter distributions were obtained to supplement the list. In the end, the announcement went out to over 4000 astronomers and astronomy departments.

The second announcement for the symposium was distributed to respondents of the first. A printed version of the announcement, as well as a color poster, were mailed to approximately 320 astronomical institutions throughout the US. It contained a preliminary meeting schedule, information on travel and accommodations, a registration form, and instructions for obtaining an abstract form for those people presenting talks and posters. The abstract form was a Latex template that allowed easy input of author names, affiliations, the title of the presentation, and the abstract itself. Crenshaw and K. Scollick (CSC) updated the GHRS Science Symposium page on the WWW to provide an interactive registration form. Text versions of the registration and abstract forms were also provided. GIF images were placed on the page to display the poster artwork, the locations of buildings in which symposium activities would occur, and a local map of the area.

A total of 61 abstracts were received by e-mail, 20 from the invited speakers and 41 from the poster presenters. The abstracts were extracted, edited where necessary, and processed through Latex into an abstract booklet. They were also converted to HTML and placed on the symposium WWW page.

Crenshaw and Drexler made arrangements for GSFC entrance badges for the symposium participants. Special arrangements were made through the GSFC Office of the Director to obtain an entrance badge for a citizen of the People's Republic of China, and an escort was identified. Ake worked with Creative Management Associates in making travel arrangements for the invited speakers. Airline tickets, car rentals, and hotel rooms were all prepaid for the speakers to minimize their carrying expenses. Bradley and Drexler made poster identification cards and registration signs, and assisted in the registration of participants at the reception and the meeting. Ake arranged for J. Bedke (CSC/STScI) to take a group photograph for the proceedings book.

The GHRS Science Symposium was held held on September 11–12, 1996. There were a total of 144 registered scientists from the US, Canada, Europe, India, and China, as well as journalists G. Vogel (Science Magazine) and R. Cowen (Science News). A total of 19 review talks and 41 posters were presented at the meeting.

Ake made preparations for producing the GHRS Science Symposium proceedings. As the proceedings will be published as a volume in the Astronomical Society of the Pacific (ASP) conference series, he obtained the style files and editor's instructions required by the ASP. Ake updated the instructions, templates, and manuals for the meeting participants to use in preparing their papers. He worked with Petersen to set up and test the anonymous FTP download and upload sites on `miranda.colorado.edu`, where users were to obtain these files and upload their completed Latex and encapsulated postscript files. The invited speakers and poster presenters were notified to prepare and submit their papers by November 1.

2 Data Analysis Facility – Subtask 2

The GHRS Data Analysis Facility (DAF) at GSFC was responsible for archiving the IDT data, updating and maintaining configuration control of the GHRS IDL team software, maintaining the GHRS data bases, supplying general software support, and providing data reduction and analysis assistance to the IDT members and their research associates and assistants. The DAF staff included Blackwell, Bradley, Crenshaw, and Sandoval.

2.1 Facility Management

Blackwell provided semi-annual reports on the status of the DAF. He summarized the status of each VMS, Unix, PC, and Macintosh computer, tabulated disk usage and available storage space, and listed new hardware obtained over the reporting period. He also provided data archive and visitor statistics, identified processing problems, and documented the installation of new software packages, software configurations, and new IDL procedures, calibration files, and data bases. Blackwell maintained a directory of office locations and phone numbers for local members of the team and the SSC, and assisted in relocating phone numbers and computers when office moves were made.

Blackwell or Crenshaw attended weekly cluster and monthly Computer Resource Allocation Board meetings to gather information on computer hardware and software changes in the LASP that could affect the GHRS project, to share information on common problems that could be experienced by different projects in the lab, and to register concerns and requests as needed. Informal contacts were also maintained with computer systems personnel in the LASP.

Staff members helped maintain the team library in the DAF room. A complete collection of documents was maintained on the instrument performance and calibration, including the GHRS science verification reports, post-COSTAR calibration reports, the STScI Instrument Science Reports, and Ball System Engineering Reports. Manuals from the STScI for preparing proposals, reducing data, and using the STScI archive were ordered for each observing cycle. Updated IDL and DAF manuals were placed in the terminal room. Paper copies were kept of the GTO proposals, archive logs, tape listings, and SMS summaries.

In September 1994 and 1995, government furloughs threatened to shut down GSFC, and thereby, the GHRS DAF. Ake made arrangements to transition GHRS SSC activities to the CSC *IUE* Greentec I facility. Temporary office space and computer accounts on the IUEGTC VAX were established. Off-site work plans were updated for all subtask areas to minimize the impact to on-going activities. Crenshaw notified the GHRS team that the GHRS computers might be inaccessible as well. Shutdowns did occur in 1995 on November 14–7 and December 18–31, but the GHRS group continued to work at GSFC since office space and the computers remained available. The DAF computers remained available for team use without interruption. Ake held discussions with T. Gull (GSFC) about the impact of the furloughs on team activities, for a report to the center Director.

Near the end of the contract period, Crenshaw compiled a list of hardware and documentation requirements to continue a scaled-down version of DAF operations. The main activities of the follow-on DAF were to continue archiving GHRS GO data as they became available through 1997–1998, and to make the data available to the GHRS team and the astronomical community through the GHRS archive on the World Wide Web. Crenshaw's list included recommendations for relocation of DAF hardware and equipment into the LASP Data Analysis Facility and other locations in the lab.

2.2 GHRS Archive

Task members continued to retrieve, process, and archive GHRS, FOS, and WFPC2 GTO data for team members as they became available from the STScI. Proprietary GO data obtained by IDT members or their collaborators were also retrieved upon request by an IDT member and by arrangement with the STScI. Procedures were implemented to retrieve all data electronically via FTP using STScI's archival retrieval system, StarView. Quality control checks were run on the data and they were acquired into the appropriate data bases. The DAF staff also continued to retrieve and archive GTO parallel data obtained with the WFPC2. Beginning in August 1995, GO UV parallels, which were immediately non-proprietary, were retrieved and archived; this practice was discontinued in mid-1996 due to limited storage space and easy access to the UV parallels from the STScI.

In February 1994, Blackwell and Sandoval began acquiring all releasable data taken by GOs into the team archive. Blackwell used StarView to list all data files and compared this to the entries in GHRSLOG to find which data sets needed to be ordered. Sandoval independently created a list of GO observations using the GHRS products generated when each SMS is made public. These lists were compared and discrepancies resolved, such as when observations failed, so that a complete and comprehensive list of observations in chronological order could be made. Blackwell began retrieving data from the STScI on a proposal-by-proposal basis, and Sandoval checked and acquired files. Sandoval made extensive modifications to this process over the next few months to more fully automate it. Crenshaw began sending monthly messages to the team to announce the availability of the new data sets. By May 1994, all of the available non-proprietary observations up to then had been obtained. Subsequently, GHRS GO data were obtained monthly as they became releasable. This process will continue until February 1998, at which time all GHRS data will be in the archive at GSFC. In total, 8204 GO, 824 GTO, and 4025 calibration data sets taken with the GHRS were archived from December 1993 through December 1996. In addition, 203 FOS and 134 WPFC2 GHRS IDT exposures and 1168 WFPC2 parallel-field images were archived.

To automate the retrieval of data from the GSFC archive after the end of the GHRS SSC, DAF staff members investigated how to make the archive available via the WWW. The design was to allow anyone the ability to access the team archive who had locally ported the team's IDL library. Since the LASP had no plans to maintain the VMS cluster of DAF workstations, the Unix machine HRSSUN, which was already in use for the IDT home page, was chosen as the site for the final archive. A disk farm was ordered and installed by ACC for storage of the GHRS acquired files, data bases, software, etc. The relevant files were converted to IEEE format and copied from the VMS cluster to the disks on HRSSUN. Crenshaw updated the existing data base search facility on the GHRS WWW page so that specific observations could be selected for transfer. Crenshaw, Ake, and Robinson also tested off-line several versions of the IDL programs written by ACC which would pack the observations into a single data set for transfer to the user and then unpack the observations when the transfer had been completed.

Crenshaw and Scollick completed a prototype version of the WWW interface for testing. It allowed a user to search the GHRSLOG data base and select data sets of interest. The mechanism for data transfer involved packing all requested data sets into a single FITS file, which would be downloaded to the user's home directory and unpacked into standard GHRS acquired files. Crenshaw and Feggans demonstrated the software during the poster session at the GHRS Science Symposium. The system successfully found and retrieved all of the data specified by participants. After the data were retrieved, representative data sets were unpacked and calibrated, and the resulting spectra were plotted for visual inspection by the participants. A number of people who use IDL for the reduction of *HST* data expressed interest in using the final version of the GHRS archive on HRSSUN.

The final version of the GHRS archive search interface was completed in December 1996, after the operating system for HRSSUN was upgraded to Solaris. It was moved to the main home page under the category "GHRS Archive on the World Wide Web". The output from a search gives the file size (in Mbytes) for each entry and the total size of the data request about to be downloaded. A random file name is given to each FITS file, so that more than one user can use the system at the same time. The file is temporary, and is deleted from HRSSUN after a couple of days. In order to unpack the data and process it using the most recent IDL software, users need updated versions of the GHRS software distributions for various platforms (VMS, Unix, or Windows).

2.3 GHRS Team Software

DAF personnel maintained configuration control over the GHRS IDL software on the VMS computers. They were responsible for moving the software through the various stages of configuration, testing the software, and sending out announcements to the GHRS team as to its availability. In May 1994, an audit of the system was performed and work began to bring the VMS software and the HRSSUN development system into uniformity. The experimental libraries were cleaned out first. Software that had limited use, typically by only one person, was moved; obsolete procedures were deleted; and the remaining software was tested and moved to the developmental library. After several weeks of testing and routine use by team members, the relevant software was moved to the baseline directories.

Crenshaw continued to test and install new software as it became available, principally from ACC. Crenshaw and Ake also installed new calibration files (sensitivity, dispersion curve, vignetting files, dead diode tables, FOS calibration files, etc.) as they became available from Robinson and other members of the SSC, ACC, or the STScI. The DEFAULTS.TXT files were updated as necessary to ensure that the proper default values for processing data with CALHRS were used, particularly post-COSTAR sensitivity curves for data obtained after January 21, 1994. In November and December 1996, Crenshaw moved all of the procedures and calibration files out of the experimental directories and into the developmental or baseline directories, in preparation for the final software distribution.

Malumuth revised the browse tool for WFPC2 images, naming it Browse2 (or HBrowse, to get a horizontal format). This new version has an overlay which lets the user know which chip is PC1, WF2, WF3, and WF4. The user can examine each chip separately by clicking on the PC1, WF2, WF3, and WF4 buttons. Malumuth documented the new tool. and sent out an announcement of the availability of the WFPC2 parallel images and the Browse2 tool to the team.

2.4 General Software Support

In 1994, the HRS VAX was replaced with a DEC Alpha workstation running OpenVMS. Other Alpha VMS workstations were also installed for the GHRS project. In preparation for the conversion to the new operating system, Blackwell obtained and compiled versions of utility software that would be compatible with the new HRS machines. The GETIMAGE package, which allows one to read the Digitized Sky Survey (DSS) CD-ROMS, was recompiled. The DIAMONDS software, which accesses the *HST* Guide Star Catalogue CD-ROMs, was obtained from the author, E. Groth (Princeton). A number of other utility applications were installed. These included XV, which is an image viewer that can display many different image formats including GIF, XBM, and JPEG and can output, among other options, color PostScript. On the Alpha workstation DEBLUR, 24-bit images can be viewed with this utility. A version of XDVI, a TeX/LaTeX previewer, was also obtained and installed. More utility programs such as VMS TAR (like the UNIX TAR), and GUNZIP (a commonly used compression/decompression utility) were made available. Blackwell and Crenshaw distributed a message to local members of the team describing the move from the HRS VAX to an Alpha OpenVMS machine. GHRS software was tested on the Alpha machine ACHAMP to ease the transition. Blackwell obtained and compiled versions of a large number of software utilities that are used by the GHRS team. In addition, switches were incorporated in HRS startup procedures to allow people still using VAX machines to access the proper version of the utilities for their system.

Blackwell installed several software clients that gave the GHRS team access to the ever growing number of astronomical information servers accessible on the Internet. Among these clients were NCSA's Mosaic for the World Wide Web, including versions for Unix, VMS, MS Windows, and Macintosh; Gopher, running on VMS, MS Windows, and Macintosh; and WAIS, installed on MS Windows-based PCs and Macintosh computers. DAF staff also maintained the anonymous FTP site on HRSSUN. The site includes the software distributions (VMS, Unix, Windows) and a PostScript version of "A User's Guide to the GHRS Software, Version 2.1".

DAF personnel installed new versions of XStarView, the *HST* archive XWindow interface, as they became available. This version ran locally on all GHRS VMS Vax and Alpha computers as well as the Unix computers, and is typically much faster than the remote version. Task members were often the first users to test the new versions outside of the STScI, and informed the archive group at the STScI when bugs were found.

2.5 Data Bases

The GHRS DAF worked to maintain over 140 data bases that could be accessed by standard IDL data base routines. These included astronomical catalogs, archive logs for various instruments, line lists, information on astronomers and institutions, *HST* proposals, the *HST* planned and archived exposures catalogs, abstracts of technical reports and GHRS papers, etc. The HST_CATALOG data base, containing a log of archived exposures, was updated monthly. The HST_PAEC data base, containing a log of existing and planned *HST* exposures, and data bases containing abstracts and titles of accepted *HST* proposals, were updated yearly for team members to use in planning new proposals. The IDL data bases ASTROPERSONS, ASTROPOSTAL, and ASTROPLACES were updated frequently to include the latest information available from the Royal Greenwich Observatory listings of astronomers and astronomical institutions.

GHRSLOG, FOSLOG, and WFPCLOG were updated whenever data were archived. In addition, new fields were added to GHRSLOG to make it more useful. The keyword GO_GTO identified data as being GO, GTO, or CALibration observations. The keyword COSTAR identified observations as pre-COSTAR (0) or post-COSTAR (1). This information was obtained using StarView, and the GHRSLOG was repopulated. Acquisition procedures were modified to automatically populate the data base when new data were retrieved.

Two new fields were added to the GHRSLOG, FOSLOG, and WFPCLOG data bases to accommodate object classes. The first, OBJ_CLASS, made use of an enhanced set of object codes that the STScI had used through Cycle 4. Sandoval first obtained a list of keyword descriptors from StarView for each of the entries in the GHRSLOG data base. Blackwell then wrote an IDL procedure which converted these keywords to the code values, which were used to populate the OBJ_CLASS field. These codes were indexed to facilitate searches on this field. The second field was OBJ_DESC, which contained the text equivalent of the various object codes. The DBHELP procedure was modified to allow an easier examination of the possible code values. While the OBJ_CLASS and OBJ_DESC fields were originally filled from data obtained from StarView, the fields for current data were filled by the HRS_ACQUIRE routine from information in the data header records. Sandoval worked with Feggans to modify the HRS_ACQUIRE routines to read the TARDESCR keyword from the SHH file, save it in the acquired PLH file, and then populate the new OBJ_CLASS and OBJ_DESC fields in GHRSLOG.

A new keyword called FILESIZE was also added to GHRSLOG. This field gives the size of the acquired files in MBytes for a particular entry. The keyword was added so that users interested in downloading GHRS data from the WWW can determine if they have sufficient storage space for the files they wish to retrieve.

2.6 Data Reduction and Analysis Assistance

The GHRS DAF provided assistance to IDT members and their research associates and assistants in reducing and analyzing their GHRS data, and general assistance to IDT members and the general community interested in the GHRS IDL software. Many questions were handled by e-mail. In some cases, tutoring sessions were set up to provide detailed instruction for individuals. Guest accounts were maintained for visiting astronomers. From December 1993 to December 1996, the GHRS DAF provided accounts and/or instruction to about 20 visitors.

3 Extragalactic Imagery – Subtask 3

Although the majority of observations made by the GHRS IDT were spectroscopic, several programs utilized the imaging capabilities of the *HST*, usually with the WFPC2 instrument. The two main areas of interest centered on studies of extragalactic objects and analyzing and archiving WFPC GTO parallel exposures. This effort was chiefly led by Malumuth.

3.1 Analysis of R136

Malumuth assisted Heap in devising the target acquisition strategy and performing the analysis for her ERO observation of R136a, the central object in the LMC cluster 30 Dor. Images were obtained with the GHRS at the positions of R136a1, R136a2, and R136a5. The R136a1 position was the result of a 5×5 SSA peakup and was to have both R136a1 and R136a2 in the field of view. The second and third images should have been a fixed distance from the first. At first glance the images were quite confusing, mainly due to the fact that the image center was about four deflection steps off from the center of the aperture in both the X and Y directions. Malumuth wrote an IDL routine which mimicked how the GHRS makes an image of the field of the SSA to test if the images made sense for a given set of telescope pointings. This program took a model of the field of view, including all of the Weigelt number stars (R136a1–8), used the SSA dimensions to cut off light which does not enter into the GHRS, convolved the light which does get through the SSA with an assumed GHRS instrumental profile, and formed an SSA image sampled in the same way as the images obtained as part of the ERO program. There were four free parameters, the center of the SSA in X and Y with respect to the field of view for the first image, which fixed the positions for the next two images, and the center of the image in X and Y with respect to the center of the SSA. Using this program, Malumuth found good agreement with the observed image for a position where R136a1 was in the center of the SSA in Y and two deflection steps from the center in X, and the images centers were three deflection steps from the center of the SSA in X and five in Y. This position put the peak of R136a2 on the edge of the SSA, not within the SSA as planned. Because of this, when the telescope was maneuvered to the R136a2 position, about one-third of the light was still from R136a1. R136a5 was near the center of the SSA, which did exclude the light from R136a2 and R136a7 as desired.

Malumuth examined the WFPC2 images obtained as part of the R136a ERO program. He corrected the few pixels that were saturated in the 20-second exposure and combined it with the 10-second and 5-second exposures to form a single PC image of 30 Dor. R136a was near the center of this chip. Malumuth used his MPHOT program to do photometry of over 1000 stars in this field of view. He then matched the results with the results of the WFPC1 U and B photometry obtained earlier and published in Malumuth & Heap (1994). The first result was that a few stars as bright as $U = 15$ mag which appear on the PC2 image were missed in the PC1 photometry. On the B image there were 22 stars between $U = 15$ and $U = 17$ mag which were missed. These stars were overwhelmingly between 0.1 and 0.2 arcseconds from a star which was at least 1 magnitude brighter. Only a few stars were less than 0.1 arcseconds from a star brighter by more than 1 mag. This demonstrated that not only had the wings been brought in by the corrective optics, but that the resolution was better with the WFPC2 than with the WFPC1. Malumuth also found that the scatter was larger in comparing WFPC1 U photometry to WFPC2 U photometry than it was comparing the WFPC1 B photometry to the WFPC2 U photometry, despite the true color differences between the stars. This showed quantitatively, as suspected, that the B image taken with Heap's GTO time was much better than the U image taken as part of the Science Assessment Observation (SAO) program.

Malumuth used the new U band photometry to examine the luminosity and initial mass functions (IMFs) both within R136a and outside R136a. The conclusions were the same as those in Malumuth & Heap (1994). The luminosity function and the IMF were both flatter within R136a. Malumuth also created a color-magnitude diagram (CMD) using the new U band and old B band photometry. This CMD showed a tighter relation than was obtained before. This was due to the improvement in the U-band photometry over the old SAO WFPC1 data. The CMD may show a deviation from the main sequence at the low-mass end, indicating that these stars have not yet reached the main sequence.

Malumuth also helped reduce WFPC2 data obtained in parallel with FOS observations of 16 stars in R136a. These data included multiple images taken with the F439W, F547M, F814W, and F1042M filters. The images were shifted from one another because of the telescope motions used in observing the primary FOS targets. During the reduction Malumuth determined the shifts using five stars which appear in all of the images and then formed a median image for each filter. The median image was then used to remove cosmic-ray events from each image, and a final co-added image was formed for each filter. Malumuth then used the F439W, F547M, and F814W (B, V, and I) images to make a true color image of the field. This image showed that there were stars from very blue to very red in this field, which was near the outskirts of 30 Doradus. Attempts to obtain a color-magnitude diagram from the F547M and F814W images by using simple aperture photometry as well as the DAOPHOT program yielded unacceptable results.

Finally, Malumuth helped analyze GHRS SSA images of R136a1+R136a2, R136a1, and R136a3 obtained as part of Ebbets's GTO observations. The plan was to use the images to evaluate where the GHRS SSA was pointed while spectra of R136a1 and R136a3 were obtained. These images were analogous to the SSA images obtained by Heap with her observations of R136a2 and R136a5, however there were a few differences. Ebbets's images were 16×16 pixels, with pixel centers two deflection steps apart, while Heap's were all 13×13 with one deflection step in X and Y. Ebbets's were also taken with Mirror-N1 and not Mirror-N2, as were Heap's. Another difference was that the STScI had corrected the offset error between the image center and the center of the aperture since Heap's data were taken.

3.2 Eta Carinae

Malumuth worked on the PC2 images of η Carinae obtained by Ebbets as part of his GTO program. Although not an extragalactic source, η Car was of prime scientific interest as one of the best cases for studying the Luminous Blue Variable phase, a short-lived, rare state in the stellar evolution of massive stars. Malumuth examined the *HST* images to determine the positions and brightnesses of several knots which are located close to the central star. He determined that the central star had some saturated pixels, even in the 2-second exposures, making it difficult to determine the brightness of this object. At first Malumuth attempted to repair these pixels using the shape of a star located on the chip. He discovered that the central object does not have the shape of a star, being much broader than a point source. This may mean that the central star is not resolved from some nebulosity which surrounds it.

3.3 Star Clusters in M33

Malumuth worked on the analysis of WFPC2 observations of several star clusters in M33. This data included UV, U, B, and V exposures of NGC 595 as well as U, B, and V exposures of CC 93, IC 142, and MA2. These images were used to produce

$U - B$ vs. $B - V$ color-color diagrams, which were then used to estimate both the average reddening and the $E(B - V)$ for each star with U, B, and V magnitudes. The stellar magnitudes were dereddened and M_V vs. $B - V$ color-magnitude diagrams were made for each of the four clusters. The photometry was also used to plot U, B, and V band luminosity functions for CC 93, NGC 595, and IC 142. Details of the results for individual clusters are discussed below.

3.3.1 NGC 595

The cluster NGC 595 was observed in the UV as well as the U, B, and V filters. In an effort to bring the UV magnitudes into the analysis of the cluster, Malumuth plotted the flux of the stars in NGC 595 as a function of wavelength for the four filters. Overplotting the flux distribution for stars of 3 Myr from program CLUSTMOD indicated a problem with the UV absolute calibration as given in the WFPC2 image header. While the flux distribution would come close to the measured flux in the U, B, and V bands, the flux in the UV band (F170W filter) was too low by about a factor of three. With the help of C. Ritchie (STScI) and Crenshaw, Malumuth was able to recalibrate the F170W filter absolute calibration. Ritchie supplied the name of the star used by the WFPC2 team for the calibration of this filter as well as the measured counts in the images. Malumuth was able to confirm the count rate for one of the images retrieved from the STScI archive. Crenshaw retrieved an *IUE* spectrum of the calibration star from the *IUE* archive and calibrated it to absolute flux. Malumuth then integrated the flux across the filter curve of the F170W filter as given in the WFPC2 Version 2.0 handbook. He found that the value of PHOTFLAM reported in the group parameter for the PC1 chip was too small by a factor of 2.576. With the new UV calibration, the flux distributions were more reasonable. Malumuth used these new calibrations to derive the reddening law for the cluster NGC 595. He obtained a value very close to the standard galactic reddening law.

There were 561 stars detected on the V-band image, 345 on the B-band image, 272 on the U-band image, and 100 on the UV image. A total of 267 stars were common to the U, B, and V images, while 85 were detected on all four images. Malumuth compared the results of the WFPC2 B-band photometry with the WFPC1 B-band photometry of Drissen et al. (1993, AJ, 105, 1400) on the same field. Although the photometry agreed in general, there was a large scatter in the differences for individual stars. Malumuth attributed this to the difference in resolution between the WFPC1 and WFPC2. The average reddening for NGC 595 was determined to be $E(B - V) = 0.29$ based on the $U - B$ vs. $B - V$ and UV $- U$ vs. $U - B$ color-color diagrams. The brightest stars in NGC 595 had an absolute visual magnitude of about -9. This is consistent with a 2.8 Myr 85 solar-mass star. The slope of the IMF for this cluster was about -1.52, which is much steeper than that found by Drissen et al.

Malumuth then compared the flux distribution of stars of different mass and age to the four color photometry of the objects in NGC 595 which were detected on all four images. To do this, Malumuth used the Maeder mass tracks and programs ISO and CLUSTMOD. Program CLUSTMOD was used to derive the flux distribution of a grid of stars at Z=0.008, close to the metallicity of NGC 595, in one solar-mass intervals. The UV, U, B, and V photometry was converted into flux and plotted against the central wavelength of each filter. This plot included error bars based on the formal error from the DAOPHOT fits. The flux distribution of each star from CLUSTMOD was plotted over the data for various different masses. The mass that best fitted the data was then selected, and program ISO was then used to determine the effective temperature of the star with the selected mass. The results indicated an age of 2.8 Myr. Malumuth repeated the analysis for both for normal mass loss and two-times mass loss cases and found that the normal mass loss gives a better fit to the data. The effective temperatures were then used to derive the bolometric corrections. For stars with U, B, and V photometry, but no UV photometry, the effective temperatures, and hence bolometric corrections, were derived by averaging the values obtained by interpolating for each band. The bolometric magnitude was derived by adding the B. C. to the absolute V magnitude and then was plotted against log $T_{\rm eff}$. Model mass tracks plotted over the data allowed the IMF to be determined. Malumuth obtained a slope of -1.06 for the IMF of NGC 595.

W. Waller (HSTX) later estimated that the number of ionizing photons needed to excite the hydrogen and produce the Hα flux in NGC 595 is twice that which Malumuth had previously estimated as originating from stellar sources. Malumuth examined whether the number of ionizing photons could be increased by assuming a continuous starburst scenario for NGC 595. He constructed a simple model which samples an IMF with the same slope as determined for NGC 595 at several different ages (4.5, 4.0, 3.5, 3.0, and 2.5 Myr) and determined what the color-magnitude diagram should look like. This scheme was shown to increase the number of ionizing photons for the same number of stars and a similar CMD diagram. However, this scheme might lead to a discrepancy in the ratio of WR stars to O stars.

3.3.2 CC 93

While NGC 595 was the second most metal-poor cluster in the sample, CC 93 was the most metal-rich. Malumuth recalibrated the absolute photometry for CC 93 using a paper by Holtzman et al. (1995, PASP, 107, 1065). He also determined the reddening for all of the stars in the cluster which were detected in U, B, and V. The average $E(B-V)$ for the cluster is 0.2. Using the determined values of $E(B-V)$, Malumuth then plotted a series of solar abundance isochrones over the observed color-magnitude diagram, thereby establishing the age of the cluster to be about 4.5 Myr. This age is largely determined by one red supergiant star. Knowing the age, Malumuth then used the program CLUSTMOD to determine the effective temperature and the bolometric correction for the stars in CC 93. Finally, using the mass-luminosity relation, he determined the initial mass of all of the stars more massive than about 10 solar masses. This IMF, uncorrected for the presence of background stars, had a slope of -2.24, much steeper than that found for NGC 595. To make a background correction, Malumuth reduced the WFC chips of the V-band image of CC 93 using DAOPHOT. CC 93 is located very close to the center of M33, which makes the background problem very difficult since the WFC chips are covered with small H II regions and star clusters or associations. To determine the background Malumuth used a contour map of the local density of stars more massive than 15 solar masses to generate a numerical mask, which was then used to exclude high-density regions on the WFC CCD chips. Regions of above average density were then excluded from the background counts. The resulting distribution of masses was fit to a power law to get the expected number of background stars in each mass bin in the CC 93 IMF. The IMF determined in this way had a slope of -1.50 ± 0.12, which is steeper than the value of -0.92 ± 0.11 found for NGC 595.

3.3.3 MA2

The aperture correction for the photometry of MA2 was slightly different for the B band image than for the other B band images, and the color-color diagram made it seem that the B magnitudes were slightly too bright, in keeping with the aperture correction. Thus, it seemed that there was a problem with the MA2 data. Malumuth suggested that the difference was due to the fact that MA2 does not have any star as bright as the brightest stars in the other clusters. Inspection of the color-magnitude diagrams of M_V vs. $B - V$, $U - B$, and $U - V$ indicate that the B band aperture correction for this cluster should be about the same as for the other clusters. Using this aperture correction, Malumuth plotted the color-color diagram for MA2 and used it to determine the reddening for those stars which have U, B, and V magnitudes. He has then plotted the color-magnitude diagram and used the isochrones from the program ISO to estimate the mass of each star. He found an IMF slope of -2.09.

3.4 Clusters of Galaxies in WFPC Parallel Fields

Malumuth worked with Sandoval on the analysis of three clusters of galaxies which were observed on WFPC2 V and I band parallel-field images. The first was in Ursa Major and included about eight spiral galaxies, two to eight arcsec in size, and many fainter, smaller galaxies. Malumuth, devised a technique to remove a substantial number of the cosmic-ray hits on the WF chips even though there is only one image in each of two filters, and cleaned the full 4 CCD chip field of view. Malumuth and Sandoval then used the ellipse fitting routine RIPS to determine the aperture brightness and semi-major to semi-minor axis ratio of all of the galaxies in the field down to a surface brightness of approximately 24.5 mag/sq arcsec. Malumuth then constructed the luminosity function for the galaxies on the field. Malumuth and Sandoval estimated the redshift of this cluster as 0.4 by comparing the image to that of a rich cluster at that redshift published by Dressler. However, at the 185^{th} meeting of the AAS, they met someone who had a spectrum of the close pair of galaxies. The redshift of the pair is 0.75.

The second cluster was in Canes Venatici. These images were quite deep, with three 2900-sec exposures with the F814W filter and two 2900-sec exposures with the F606W filter. Malumuth cleaned the images of cosmic rays and combined them, revealing an elliptical and four spiral galaxies in a small area. The size of the largest spiral and the brightness of the elliptical both indicate a redshift of between $z = 0.1$ and $z = 0.2$. Malumuth and Sandoval searched the POSS prints for this group. The galaxies were barely visible and the group has not previously been identified. He then used these cleaned images to do aperture photometry of the six large galaxies that are the most likely members of the group. The counts were then converted into V and I band magnitudes and $V - I$ colors.

Finally, Malumuth began work on a new cluster of galaxies in Hercules found on WFPC2 parallel images. This cluster is much richer that the two groups previously found. It is also at a higher redshift, judging by the size and brightness of the galaxies.

3.5 QSO Images

Malumuth reduced the WFPC2 data of QSO 2130+099 obtained by Heap on December 2, 1994. These data consisted of exposures through the F555W, F450W, and F336W filters. The images were first cleaned using standard techniques, and then all images taken through the same filter were combined. Malumuth then used images from the STScI archive to determine the PSF through the F555W filter and subtracted the QSO from the image of the galaxy. The archive did not have a high enough S/N image of a star on the PC chip for the F450W and F336W filters, so Malumuth obtained the latest version of TinyTim from STEIS to derive a theoretical PSF for these filters. Malumuth then fit ellipses to the remaining light from a semi-major axis of 4 pixels to 145 pixels to determine the flux, x-center, y-center, axis ratio, and position angle. This was done in two ways, firstly after subtracting a scaled PSF, and then without subtracting the PSF. The flux in counts was then converted to a surface brightness in magnitudes using the prescription of Holtzman. Malumuth found an offset of about 0.25 magnitudes between the V image and Heap's published ground-based data. He also found a $B - V$ color which is close to zero. This seems very unlikely since the disk appears to be a normal spiral galaxy.

3.6 Analysis of cD galaxies in Abell Clusters

Malumuth analyzed *HST* data of the cD galaxies in clusters Abell 779, Abell 2199, and Abell 2052. He found that, although these are all cD galaxies, the luminosity distribution in their centers are quite different. The primary nucleus of A2199 and A2052 both have star-like nuclei, while A779 does not. A779 and A2199 both have cores while A2052 does not. None of these galaxies are well-fit by a single King model or $R^{-1/4}$ law, but the cD in Abell 779 can be fit with a two-component King model.

4 Extragalactic Spectroscopy – Subtask 4

Ultraviolet spectra of Seyfert 1 galaxies obtained with the GHRS and FOS were analyzed by Crenshaw under Boggess's GTO proposals 1170, 3965, 4045, and 5182, and Maran's GTO proposals 1160, 3936, 5724, and 5728. Crenshaw supported these programs by rewriting the proposals to account for adjustments in observing time or instrument capabilities, following the proposals through the scheduling process to ensure they were executed properly and on time, reducing and analyzing the data, interpreting the data in light of recent models, and presenting the results at conferences and in scientific journals.

4.1 FOS Spectra of Seyfert 1 Galaxies

The originals goals of Boggess's program were as follows:

- Deconvolve the broad and narrow components of the strong emission lines; this is extremely difficult to do with low-resolution *IUE* spectra. Determine separate fluxes from the broad- and narrow-line regions for comparison with photoionization models.

- Extract the broad-line profiles for comparison with kinematic models, and determine line ratios as a function of radial velocity to study the manner in which the physical conditions (e.g., ionization parameter) change across the broad-line region.

- Measure many of the weak UV emission lines and emission lines from optical spectra to estimate the reddening along the line of sight using the He II $\lambda1640/\lambda4686$ ratio, and to provide further clues to the chemical composition, density, and ionizing spectrum in the emission-line regions.

- Detect absorption lines from the Galactic halo, the intergalactic medium (including Lyα forest lines), and the Seyfert galaxy to establish the physical conditions and chemical composition of the gas. Any absorption lines that originate in or near the broad-line region could provide valuable information on cloud motions and the covering factor.

Originally, the observations were to be obtained over the 1150–1700 Å region with the G140L grating at a resolution of 2000, and in the Mg II 2800 Å region with the G270M grating at a resolution of $\approx 20,000$. However, with the early loss of the Side 1 detector, it was decided that the program could be switched over to the FOS with no loss in the primary scientific objectives. Observations with the FOS G130H, G190H, and G270H gratings through the $1''$ circular aperture provided coverage over the entire UV wavelength band (1150–3300 Å) at a resolution of ≈ 1000. In order to compensate for the loss of sensitivity due to spherical aberration, the number of targets was reduced from seven to five Seyfert galaxies (NGC 5548, Mrk 509, Fairall 9, Mrk 335, and Akn 120). The most interesting observations were those of NGC 5548 and Mrk 509.

Ultraviolet spectra of the Seyfert 1 galaxy NGC 5548 were obtained with the FOS on July 5, 1992, when the UV continuum and broad emission lines were at their lowest ever observed level. The high resolution of the spectra, relative to previous UV observations, and the low state of NGC 5548 allowed the detection and accurate measurement of strong, narrow components of the emission lines of Lyα, C IV $\lambda1549$, and C III] $\lambda1909$. Isolation of the UV narrow components enabled a detailed comparison of narrow-line region (NLR) properties in Seyfert 1 and 2 galaxies. Removal of their contribution was important for studies of the broad-line region (BLR). Relative to the other narrow lines, C IV λ1549 was much stronger in NGC 5548 than in Seyfert 2 galaxies, and Mg II λ2798 was very weak or absent. If the strong C IV flux was due to a high ionization parameter, then one explanation for the weak Mg II flux may be that the ionization parameter is high enough to fully ionize the NLR clouds. Another possible explanation is that dust grains are present in the NLR clouds, and the Mg II flux is weak due to depletion and/or destruction from multiple scatterings and eventual absorption by the dust. With the addition of optical lines, careful dereddening of the narrow-line regions (using the He II $\lambda1640/\lambda4686$ ratio for example), and detailed photoionization modeling, it should be possible to distinguish between some of these possibilities.

Ultraviolet spectra of the Seyfert 1 galaxy Mrk 509 were obtained with the FOS. The spectra exhibited strong absorption lines in the cores of the redshifted emission lines of Lyα and C IV $\lambda\lambda$1548.2,1550.8, confirming an earlier detection in *IUE* high-dispersion spectra, and a new detection of strong N V $\lambda\lambda$1238.8,1242.8 absorption lines, also near the redshift of Mrk 509. There was no evidence for absorption in the lines of Mg II or Si IV at the redshift of Mrk 509. The absorption lines had two components that were at the same velocities as those in the *IUE* observations obtained about 12 years earlier: one at the systemic redshift of the host galaxy, as defined by the low-ionization emission lines in the optical, and one at a radial velocity of -390 km s^{-1} relative to the systemic redshift. The equivalent widths and velocities of the absorption lines indicated that they arise from an extended region of highly ionized gas surrounding the nucleus of the host galaxy consisting of two distinct kinematic components.

FOS spectra were also obtained of Fairall 9, Mrk 335, and Akn 120. Comparison of these spectra with those obtained previously by *IUE* did not yield any dramatic new surprises. However, the high signal-to-noise data were essential for the basic measurements needed to meet the original goals of the program, as mentioned above. In particular, strict upper limits were placed on the equivalent widths of intrinsic absorption lines. When FOS spectra from the archives and GHRS spectra from Maran's program are included, the fraction of Seyferts with intrinsic absorption can be used to determine the covering factor (see below).

4.2 GHRS Spectra of Seyfert 1 Galaxies

Maran's original GTO program argued that, based on the available X-ray data, the effective covering factor by broad-line clouds should be larger (on a statistical basis) in low-luminosity AGN than in higher-luminosity AGN, and thus the probability of seeing absorption lines should be larger as well. In addition, due to the overall smaller physical scales involved, the likelihood of variations on easily observable time scales in these absorption lines should also be much higher in low luminosity AGN. X-ray observations, appear to support this idea. Combining the BLR averaged response from the *IUE* monitoring with the specific line-of-sight information from the absorption-line variability will finally allow researchers to break the intrinsic convolution one always has with emission lines. Continued monitoring of this object is necessary to obtain fundamental parameters like the "effective" number of clouds per line of sight, the "mean" transverse velocity of the clouds, and the information necessary to distinguish between variations in the cloud number/density in the line of sight and variations in optical depth due to ionization changes.

Originally there were four targets selected for GHRS observations on the basis of strong and/or variable X-ray absorption: NGC 3783, NGC 3516, NGC 3227, and NGC 1566. Observations with the G140L and G270M gratings were planned at four different occasions for each target. Due to an observing efficiency that was lower than expected (partially as a result of spherical aberration), the program was modified a number of times, although some of the observing time was recovered with an augmentation proposal. Eventually, the program consisted of three separate visits to NGC 3783, separated by one-year intervals, and two visits to NGC 3516, separated by six months. Observations were obtained with the G160M grating of the C IV region through the Large Science Aperture at medium resolution ($\lambda/\Delta\lambda \approx 20,000$).

Variable absorption lines were found in the GHRS spectra of the Seyfert 1 galaxy NGC 3783. C IV $\lambda\lambda$1548.2,1550.8 absorption was present in an FOS spectrum on July 27, 1992 and a GHRS spectrum on January 16, 1994 at a radial velocity of -450 km s^{-1} relative to the emission-line peak, but there was no evidence for absorption in a GHRS spectrum on February 5, 1993. A GHRS spectrum on February 21, 1993, obtained just 16 days after the spectrum with no detectable C IV absorption, showed strong N V $\lambda\lambda$1238.8,1242.8 absorption lines, also at a radial velocity of -450 km s^{-1}. The observations placed constraints on the two types of models for absorption-line variability: bulk motion into the line of sight, and variable ionization of gas already in the line of sight. If the C IV absorption-line variability were due to changing ionization, it would have been unlikely that a change in distance from the continuum source was responsible. It is more likely that a significant change in ionization resulted from a large change in luminosity of the central source in the EUV continuum, which triply ionizes carbon. Another possibility is that the C IV absorption-line variability is related to changing ionization in the "warm absorber" component seen in X-ray spectra of NGC 3783, although a direct connection between the UV and X-ray absorption regions has not yet been established.

The GHRS spectra of NGC 3516 showed the C IV doublet at four distinct radial velocities in the core of the C IV emission line. One component was at the systemic radial velocity of the host galaxy, indicating that it may arise from the interstellar medium in this Seyfert galaxy. The other three components were blueshifted with respect to the systemic radial velocity, indicating outflow. Two of the blueshifted components were broad, $\sim$ 100 km s^{-1} FWHM, and had depths near the zero-intensity level. GHRS spectra obtained six months later indicated a possible small change in one of the absorption components, but the change may also be due to a variation in the underlying broad emission. There was no evidence for absorption from low ionization lines, such as Mg II, in the FOS spectra of this object. The column density of C IV is too large to be produced in the high temperature ($\sim 10^5$ K) gas that produces the O VII and O VIII absorption edges in the X-ray region.

4.3 Intrinsic Absorption in Active Galaxies

FOS spectra obtained under Boggess's program and GHRS spectra obtained under Maran's program, along with a few observations in the *HST* archives, indicate that at least 50% of Seyfert 1 galaxies show intrinsic UV absorption lines. The intrinsic absorption lines in the *HST* spectra had a number of similar properties:

1) They were all blueshifted by 0 to -1500 km s^{-1}, which indicates net radial outflow.

2) Many of the C IV absorption components were moderately broad, 100–300 km s^{-1}, indicating macroscopic motions, since a temperature of $T = 10^5$ K would produce a thermal width of only 20 km s^{-1} FWHM. In addition multicomponent profiles were common.

3) High-ionization C IV$\lambda\lambda$ 1548.2,1550.8 and N V $\lambda\lambda$ 1238.8,1242.8 lines were always present. The O VI $\lambda\lambda$ 1032,1038 lines have been detected in HUT spectra of NGC 4151 and NGC 3516. Low-ionization lines, such as Mg II λ2796.4,2803.5, have not been seen, except in the case of NGC 4151.

4) The absorption lines were variable on time scales of weeks to years, and possibly days. There was evidence for both variable ionization and bulk motion in NGC 3516.

5) The cores of the strongest absorption lines were deeper than the continuum heights. In some case, the absorption lines went to zero intensity, which indicates that the absorber was completely outside of the broad emission-line region.

6) Comparing different objects, there was a large range in C IV column density; for example N(C IV) $\approx 10^{14}$ cm^{-2} in NGC 3783 and N(C IV) $\approx 10^{18}$ cm^{-2} in NGC 3516. The former was at least consistent with the column densities expected from a single-zone warm absorber, but the latter was not.

For those objects with good *ASCA* spectra, there was a close correspondence with "warm absorbers", which were characterized by highly ionized gas (O VII and O VIII absorption edges). However, at least one object, Mrk 509, showed UV absorption lines but no X-ray absorption. It has been proposed that the UV absorption lines are from "trace" ions (C IV, N V) in the warm absorber gas. However, in the cases of NGC 4151 and NGC 3516 the column density of C IV was too large to be produced in a single zone characterized by the warm-absorber ionization parameter. Thus, a range in absorber properties and locations, relative to the central continuum source and broad emission-line region, was indicated. In order to pin down the origin and physical properties of the UV absorber, variability monitoring in the UV at moderately high resolution is needed. The lag between continuum and absorption variations gives the recombination time, which results in an estimate of the density. From the ionization parameter determined with the help of photoionization models, the distance of the absorber from the central source can be determined.

5 Cool Stars – Subtask 5

The GHRS program for cool stars entailed the observational and theoretical investigation of chromospheres, coronae, and coronal activity, such as flares. Robinson and

Airapetian initially worked on the projects in these areas for Carpenter, Maran, and Woodgate. This work expanded into other fields involving binary stars.

5.1 Giant and Supergiant Non-Coronal Stars

This was the primary GTO/GO program for Carpenter and research in this area was the responsibility of Robinson.

5.1.1 Atmospheres of Normal Giant and Supergiant Stars

Studies of the atmospheric structure and dynamics of normal giant and supergiant non-coronal stars by Carpenter and Robinson centered on four stars: the M supergiant α Ori, the M giant γ Cru, the K giant α Tau, and the K supergiant λ Vel. Together, these stars sample a large portion of the upper right-hand portion of the HR diagram and allow studies of atmospheric variations as a function of effective temperature and luminosity.

One of the most significant results of this study involved the investigation of atmospheric flows and turbulence. In all cases the spectra of these stars contain numerous Fe II emission lines, most of which are centrally reversed. The wings of these lines are formed low in the atmosphere, while the reversals are formed in the higher layers, where the optical depth of the line approaches unity. By careful analysis of the lines Robinson discovered that the wings had a relatively small radial velocity with respect to the stellar rest frame, with most stars showing a slight inflow. However, the absorption features showed a blue shift which increased with the relative strength of the line. This behavior indicated an acceleration of the wind with height through the chromospheric regions where these Fe II lines are formed. This acceleration was also seen in other lines, such as the Mg II and O I resonance lines, which are formed at higher layers than the Fe II lines. Of the four stars examined in detail, Robinson found that the wind signature was greatest for the M giant γ Cru. In this star the wind appears to originate low in the atmosphere and accelerates to values of about 15 km s^{-1} in the regions sampled by the strongest Fe II lines. In contrast, the K giant α Tau shows no evidence for a wind except in the very strongest Fe II lines. In this star the wind signature is mainly seen in the O I and Mg II line profiles, suggesting that the acceleration is initiated at relatively large heights in the atmosphere. Robinson is currently working with the TLUSTY code, developed by Hubeny, to develop realistic atmospheric models for these stars and to quantitatively determine the height of wind onset and the acceleration of the wind as a function of height.

It is normally assumed that the mass-loss rate from these cool, luminous stars varies by small amounts, if at all. However, when Robinson, Carpenter, and Mullan (Bartol) compared an *HST* spectrum of the K supergiant λ Vel taken in 1994 with a similar *IUE* spectrum taken in 1990, they found substantial changes in the Fe II line profiles. While the *HST* observations showed normal, centrally reversed Fe II lines with a slight excess in the intensity of the red peak, the *IUE* data had Fe II lines in which the blue portion of the profile was almost completely gone. Assuming that the line asymmetries were the result of scattering in a spherically expanding wind, Mullan and Robinson used the SEI computer code to show that the change in profile could be explained by a change by a factor of ten in the wind opacity, implying that the mass-loss rate decreased by a factor of ten between 1990 and 1994. The profile changes were seen at a velocity of 100 km s^{-1} from line center, which suggested that the star has a much larger wind terminal velocity than had previously been suspected. In fact, a close examination of the Mg II line by Robinson and Mullan showed that the actual terminal velocity is probably closer to 280 km s^{-1}. Robinson has examined the Mg II profiles for a large range of cool, luminous stars and showed that a large wind terminal velocity may, in fact, be a common characteristic of this class of star.

Robinson and Carpenter investigated chromospheric macroturbulence using the profiles of optically thin emission lines, such as the C II] and Si II] intercombination lines and fluorescent lines of Fe I and Fe II. The turbulence was found to increase with stellar luminosity, going from 24–27 km s^{-1} for the K and M giants to 34–37 km s^{-1} in the K–M supergiants. The profiles were also found to have large wings, which Robinson and Carpenter have interpreted as being caused by an anisotropic distribution of velocities, such that the turbulence is preferentially directed either parallel or perpendicular to the stellar radius.

The large turbulent velocities are highly supersonic and may give clues to the heating of the atmosphere and the mechanisms which drive the stellar wind. Robinson and Carpenter worked with P. Judge (HAO) and M. Cuntz (CASA) on observations aimed at determining whether stochastic acoustic shocks may be responsible for the observed macroturbulence. According to *ab-initio* calculations carried out by Cuntz, these shocks will interact with one another and cause substantial variations in the local turbulence on time scales of hours to days. However, examination of C II profiles on α Tau which were taken approximately 12 hours apart shows no indication of measurable changes in the profiles. Further, most of the shock calculations predict turbulent velocities which are substantially smaller than those observed. Airapetian and Robinson have therefore been examining an alternative theory which involves non-linear Alfv̌en waves. Theories which have used linear Alfv̌en waves to explain chromospheric heating and wind acceleration have been around since the mid 1980s. However, they have generally involved highly non-realistic assumptions. Recently, L. Ofman (HSTX) and J. Davila (GSFC) have been investigating the behavior of these waves in solar coronal holes using a fully consistent three-dimensional magnetohydrodynamics code. This code indicates that waves generated by the stellar convection motions in the photosphere can steepen as they propagate upwards and will eventually become non-linear. At some point the velocity shears will become sufficiently large so that Kelvin-Helmholtz instabilities are initiated and large amounts of magnetic turbulence are formed. This turbulence can damp through viscous or ohmic processes to heat the atmosphere and may also transfer momentum which will drive a wind. Airapetian has worked with Ofman in applying the code to the case of giant and supergiant atmospheres. The calculations are still in preliminary stage. However, preliminary indications suggest that this process may account for the large turbulence seen in these stars as well as the observed wind velocity and mass loss rate. The question of whether these waves can provide sufficient atmospheric heating is still unanswered, however.

5.1.2 Hybrid Stars

Robinson and Carpenter were co-investigators on an *HST* proposal to observe the K5 giant star γ Dra, with A. Brown (CASA). This star is a known hybrid and has a spectral class which is identical to the "normal" K5 giant α Tau, which was extensively observed during Carpenter's GTO and GO programs. Robinson combined the two *HST* data sets to investigate the physical differences between the two stars. Surprisingly, this comparison showed that the lower atmosphere of the two stars is almost identical. For example, when the UV fluxes are scaled by the ratio of the V band luminosities, the continuum intensities were found to agree through the entire range from 1200–2800 Å. The Fe II emission line profiles agree very well and the C II] intercombination lines show that the two stars have almost identical chromospheric macroturbulence. Surprisingly, a deep exposure near 1550 Å on α Tau indicated the presence of C IV emission with a surface flux which is nearly the same as that on γ Dra. This was unexpected, since the presence of transition region material is normally taken as a characteristic of the hybrid class of stars. The 1550 Å region of α Tau also showed the presence of narrow emission lines caused by Lyα fluorescence of Fe II. These emission lines were not present in the γ Dra spectrum and indicate that the upper atmosphere of α Tau is probably denser than that of γ Dra. The primary difference between the two stars occurs in the upper atmosphere, seen primarily in the O I and Mg II lines in the *HST* observations. These lines indicate that the hybrid star has a wind which is both faster and has a larger optical depth than the normal star. How such a strong difference in the outer atmosphere can exist given the similarities in the lower atmosphere is still under investigation.

5.1.3 Cepheid Masses

Robinson and Carpenter collaborated with N. Evans (CFA) and E. Böhm-Vitense (U. Washington) on the determination of the masses of Cepheids. In this program the Cepheids are in a binary system with a hot, main-sequence star, such that the Cepheid will dominate the spectrum in the visual, while the main-sequence star dominates in the UV. By comparing the orbital radial-velocity variations for the two stars a mass ratio can be determined. The mass of the hot companion is then determined from its spectral type and the Cepheid mass is thereby deduced. The Cepheid mass and luminosity provide important tests of the core-convective overshoot in evolutionary models of intermediate mass stars. Robinson was primarily responsible for the data reduction and calibration. Thus far results have been obtained on three Cepheids: S Mus, V350 Sgr, and Y Car. The masses derived for these stars were 5.9 ± 0.7, 5.0 ± 2.0, and $4.1 \pm 1.0 M_\odot$ respectively. These masses suggest that core-convective mixing can be important during the main-sequence evolution.

5.1.4 Barium and CH Stars

Robinson, Ake, and Carpenter collaborated with Böhm-Vitense on a program to search for the presence of white-dwarf companions to stars with anomalously high barium or CH abundances. The theory is that these stars acquired their abundance anomalies during the post-main-sequence evolution of the companion. A total of 13 stars have been observed thus far, including three standard stars. The observations were obtained with the G140L grating, covering the wavelength range from 1285–1560 Å and used the rapid readout mode so the background noise could be minimized. Robinson and Ake have worked on the data reduction and Robinson is currently working with Böhm-Vitense in analyzing the data. A weak continuum, with a maximum flux of 2.0×10^{-16} erg cm^{-2} s^{-1} $Å^{-1}$, was seen in all of the stars. However, the spectrum in the barium and CH stars was found to be very close to that of the standard stars in all cases. Thus, either the systems are older than expected, so that the white dwarfs are cool, or there are no white dwarfs present and the current theory must be re-examined.

5.1.5 RR Tel

Carpenter and Robinson collaborated with G. Harper (CASA) on a study of the symbiotic star RR Tel. The spectra consist of numerous emission lines, many from forbidden transitions, which are superimposed on a weak continuum. Many of the lines have important astrophysical applications and the main purpose of the project was to determine basic atomic parameters of these transitions, including electron collision strengths, branching ratios and recombination rates. Robinson was responsible for the reduction and calibration of the data and has been working with Carpenter and Harper on determining accurate wavelengths, integrated fluxes, and line identifications for all of the observed emission lines. A paper describing the data has been written and work is in progress on a second paper describing the deduced atomic parameters.

5.2 Stellar Activity

5.2.1 RS CVn Stars

Robinson, Airapetian, and Maran completed a study of the active RS CVn star HR 1099. This project involved GHRS observations obtained as part of Maran's GTO program. These observations consisted of eight rapid-readout time sequences, each of 30-minutes duration, taken with the G160M grating in the region centered at 1360 Å. This region contains emission lines of O I, C I, Cl I, Fe II, O V, and Fe XXI formed at temperatures ranging from 10,000 K to more than 10 million K. Integrating the spectra over each orbit and comparing the individual spectra showed a changing radial velocity which was fully consistent with the radial-velocity variations of the primary star, suggesting that most of the emission comes from the primary. This was confirmed by a detailed examination of the spectra, which showed no indication of emission at the radial velocity of the secondary for any of the chromospheric (O I, Cl I, C I) or transition region (O V) lines. The Fe XXI line at 1354 Å, however, did show an excess emission from the secondary, which contained approximately 25% of the total observed flux. This suggests that hot coronal plasma has been supplied to the secondary from the primary star, probably along interconnecting magnetic field lines. All of the emission lines were fully resolved and had widths which were much larger than expected from purely thermal and rotational broadening. Assuming that the excess width results from macroturbulence, it was found that this turbulence increased with height from values of less than 30 km s^{-1} in the chromosphere to about 150 km s^{-1} in the transition region. The turbulence then decreases into the corona, where the values must be less than 65 km s^{-1} to be consistent with the Fe XXI profile. The shape of the line profiles also suggests that this turbulence has an anisotropic velocity distribution, with the motions directed preferentially either along or perpendicular to the radial direction. Robinson and Airapetian used these observations to place constraints on models for the coronal structure and atmospheric heating. It was found that the corona of the primary is unlikely to extend to heights greater than 2.3 stellar radii and most likely is confined within magnetic loops with lengths of about 3×10^{10} cm having an electron density of 1×10^{10} cm^{-3}. While it is possible that the atmospheric heating may be caused by numerous microflare events, as suggested by other authors, the GHRS data showed little evidence for such an interpretation. Instead, Robinson and Airapetian investigated the possibility that the atmospheric heating is caused by the initiation of Kelvin-Helmholtz instabilities by non-thermal Alfvén waves. Simple calculations show that such a process can account for the heating using the observed turbulence, and it can also approximately reproduce the variation of the turbulence with height.

5.2.2 Stellar Flares

Robinson worked with Carpenter on a project to determine whether microflare activity is responsible for the atmospheric heating of active cool dwarf stars. The data consisted of HSP time sequences taken on the dMe stars YZ CMi (dM4.5e) and CN Leo (dM8e) through a wide band filter centered at 2400 Å, where the stellar photospheric flux is negligible. For CN Leo a total of 32 events were detected over an on-source observing time of two hours, many of the larger events showing more fine structure than typically observed in the optical. This may be caused by the fact that the UV continuum occurs mainly during the explosive phase of a flare and therefore lasts a much shorter time than the optical continuum. For YZ CMi a total of 54 identifiable microflare events were observed in 2.5-hours of on-source observing. In addition, while CN Leo had a "quiescent" near-UV (NUV) count rate of about 4 counts s^{-1}, the background level for YZ CMi ranged from 90 to more than 150 counts s^{-1} during the observations. The photospheric flux at 2400 Å is nearly zero for both stars, so the background NUV count rate directly reflects the amount of chromospheric activity. The fact that the NUV count rate scales with the known quiescent X-ray emission from the stars also suggests that chromospheric and coronal heating result from the same physical process.

Robinson calibrated the microflare events in energy and compared the distribution with that observed in ground-based optical data. The smallest reliable flare energies observed by the *HST* were more than an order of magnitude smaller than the detection threshold for ground-based data. The relationship between the occurrence rate and energy for the microflares was found to be a power law with a shape which was identical to that found for larger flare events observed in the optical. However, extrapolating this relationship to lower energies predicted far too few events to account for the observed background NUV emission, especially in the case of YZ CMi. Thus, it was concluded that either microflares are not the source of chromospheric and coronal heating or that the occurrence rate for the microflares increases by an order of magnitude or more at the smallest energies.

Robinson and Airapetian also collaborated with Woodgate and Carpenter on a large coordinated observing campaign of the dMe flare star YZ CMi, carried out in December 1994. This campaign was built around Woodgate's GHRS GO observations of this star, which were designed to follow up an earlier detection of proton beams during the impulsive phase of a flare on AU Mic. In addition to the *HST* observations the campaign included data from the *IUE* and *EUVE* satellites, as well as optical ground-based spectroscopy from the 3.8-m Anglo-Australian Telescope, the 36-in, 82-in, and 107-in telescopes at McDonald Observatory, the Lick 120-in telescope, and radio observations from the VLA and the Australia Telescope. The GHRS data were obtained in rapid readout mode using the G140L grating and covered the wavelength range from 1150 to 1440 Å. In analyzing this time sequence, Robinson identified a total of 31 flare events during the 7.5 hours of on-source observing, spread over 11 orbits. Robinson found that the quiescent spectrum showed lines formed over a wide range of temperatures, including Lyα, Si II, Si III, Si IV, C II, C III, N V, O V, and Fe XXI. During flares these lines increase in strength. However, contrary to the case for solar flares, where much of the energy is deposited at very high temperatures, on YZ CMi Robinson found that all of the flares had the greatest increase in lines formed at temperatures of around 60,000 K (i.e., Si III and C III). Lines formed at lower temperature (e.g. C II, O I) and higher temperatures (e.g., N V, O V, and Fe XXI) had relatively smaller increases during the flare. The implication that no coronal enhancements occurred was confirmed by simultaneous *EUVE* data, which showed no flux increases during any of the events. Robinson also found that the line variations were normally accompanied by variations in the far-UV continuum flux, although there does not appear to be a simple relationship between the relative strengths of the line and continuum fluctuations. A spectrum of the continuum shows a slight increase towards longer wavelengths. Airapetian has modeled this spectrum and concludes that the continuum is optically thin and formed at a temperature of not more than 21,000 K in a region with particle densities of not more than 1×10^{15} cm^{-3}. Unfortunately, the large continuum variations limited the detectability of proton beams and Robinson found no evidence for proton beams in any of the observed flares. Finally, Airapetian analyzed the relative line strengths during a flare and determined from various line ratios that the emission lines are optically thin in the quiescent spectrum but can become optically thick during a flare. When this occurs the lines saturate and it becomes possible to estimate the size of the event, which was found to be at most a few percent of the stellar surface area. From this data Robinson and Airapetian have developed a model for these events which suggests that the flares are formed within low lying magnetic flux tubes having electron densities in excess of

1×10^{12} cm^{-3}.

6 Stellar Abundances – Subtask 6

Work on the stellar abundances subtask primarily supported the GTO programs of Leckrone and Brandt for observations pertaining to the chemically peculiar (HgMn) stars χ Lupi, κ Cancri, and HR 7775, as well as analyses of SMOV and calibration observations of these same targets. The primary scientific purpose of these programs was to use the high-resolution and signal-to-noise capabilities of the GHRS to study the ultraviolet spectrum of one HgMn star in as much detail as possible, to sample other HgMn stars at selected wavelength regions pertaining to the study of the element Hg, and to test theories of the origins of the abundance, ionization, and isotopic anomalies seen in these stars. It has long been assumed that these anomalies are caused by the selective effects of radiation pressure from photons absorbed by strong transitions of individual ions. However, the lack of both comprehensive observations and sufficiently accurate atomic data has made quantitative tests of this paradigm difficult, especially for the heaviest elements that show the largest anomalies. The GHRS data offered a unique opportunity to improve this situation. Most of the GHRS observations concentrated on one star, χ Lup, but additional GTO observations were obtained later for another HgMn star, HR 7775. This star has an effective temperature and surface gravity very similar to those of χ Lup, but shows striking differences in many of its abundance anomalies. Careful comparison of these two stars may offer useful clues to the causes of the anomalous abundances.

Support for this subtask was primarily supplied by Wahlgren, Proffitt, and Brage. Work included planning of GTO observations (including preparation and submission of Phase 2 proposals), reduction and analysis of the resulting GHRS data, calculation of synthetic spectra, classical LTE abundance analyses, non-LTE modeling of stellar atmospheres, calculation of radiative forces, and theoretical atomic physics calculations in support of the other activities. Close collaboration of CSC staff with astronomers and experimental atomic physicists from the Citadel, University of Lund, the National Institute of Standards and Technology, and Queen's University in Belfast was also an essential part of this task.

6.1 Observational Work and Spectrum Synthesis

Proffitt and Wahlgren, in consultation with Leckrone, prepared and submitted the Phase 2 proposals for Cycle 6 GTO observations of chemically peculiar stars. These consisted of an eight-orbit proposal for Leckrone (GTO 6245) and a twenty-orbit proposal for Brandt (GTO 6275). Work was also done on evaluating strategies for observing chemically peculiar stars with STIS, with the goal of continuing the current peculiar star observing program with GO observations in future *HST* observing cycles.

Newly available software to compute LTE plane-parallel model atmospheres (ATLAS) and synthetic spectra (SYNTHE) were obtained and installed on the GHRS VAX machine. Testing was conducted to ensure that the new codes operated in a correct manner before replacing the older versions, which were more awkwardly run on the GSFC IBM mainframe computer.

Analysis of GHRS observations of HgMn stars was the largest part of this task, with optical and *IUE* observations providing additional data. Wahlgren, Proffitt, and Brage, in close collaboration with Leckrone and S. Johansson (Univ. of Lund), among others, played a major role in using the GHRS spectra to determine chemical abundances of the program stars. Their work on this task led to papers on the stellar abundances of ruthenium (Johansson et al. 1994), arsenic (Wahlgren et al. 1994), platinum, gold, and mercury (Wahlgren et al. 1995), thallium (Leckrone et al. 1996), palladium (Lundberg et al. 1996), and rhenium (Wahlgren et al. 1997). Other papers dealing with bismuth, lead, tungsten, osmium, rhodium, strontium, zirconium, and yttrium were submitted or are in progress. In addition to papers published in refereed journals, dozens of contributed papers and conference talks were presented by the task members on a wide range of topics related to *HST*, the GHRS, and the chemically peculiar star GTO program. A summary of the abundance determinations to date was recently presented by Leckrone et al. (1997) at the GHRS Science Symposium.

The most dramatic progress occurred in elucidating the abundances of the heaviest stable elements. Previously, only the most overabundant of these could be measured. By combining theoretical and laboratory atomic physics data with GHRS observations, team members helped to fill in the abundance distribution of χ Lup between tungsten ($Z = 74$) and bismuth ($Z = 83$). The resulting distribution exhibited a rather smooth curve with a peak near mercury, although it is not clear why the elements platinum ($Z = 78$) through thallium ($Z = 81$), should have dramatically higher abundances than slightly lighter or heavier elements. HR 7775 showed similar abundances of many of these elements, but some were quite different. Bismuth in χ Lup, for instance, was at most 50 times the solar system abundance, but it is 100,000 times solar in HR 7775.

In addition to abundance analyses, isotope ratios in the HgMn stars were extensively studied. It has long been known that mercury in the cooler HgMn stars is strongly weighted towards the heaviest isotopes. Chi Lup is one of the most extreme cases, with 99% of the mercury in its atmosphere being in the form of ^{204}Hg (as opposed to 7% in the solar system). Task members helped to demonstrate that the same isotope anomaly is seen in all visible ionization stages of mercury in χ Lup, in contradiction to the predictions of some diffusion models. Other work helped to demonstrate that a similar isotope anomaly exists for thallium, as do somewhat less extreme isotope anomalies of platinum and osmium. Preliminary work on HR 7775 showed that, at least for platinum and mercury, its isotope anomalies are significantly less extreme. The GHRS observations of the hotter HgMn star κ Cnc were found to be consistent with optical region findings showing the Hg isotopic mixture to essentially be terrestrial in this star (Wahlgren et al. 1995).

Additional analysis will be continued, with further work on mercury a high priority. The resonance lines of Hg I imply an overall mercury abundance seven times smaller than that found from the resonance lines of Hg II, and while Hg III lines imply much larger abundances than do those of Hg II, the size of the anomaly found from different Hg III lines varies considerably. The proper interpretation of this is as of yet unclear;

however, one significant clue is that the Hg II and Hg III lines observed in HR 7775 show smaller isotope and ionization anomalies than those observed in χ Lup. That such substantial differences can be found in the ionization ratios in two stars with nearly identical effective temperature argues strongly against non-LTE effects as their primary cause.

In order to more fully characterize the abundance anomalies in the observed GTO program stars, it was deemed necessary to acquire ground-based optical spectra. Previous optical studies for χ Lup, HR 7775, and κ Cnc had been limited in their wavelength coverage, signal-to-noise ratio, or scope of the analysis. Optical spectra were obtained by Robinson, for χ Lup using the Anglo-Australian Telescope, and Wahlgren, for κ Cnc and HR 7775 using the Nordic Optical Telescope. An elemental abundance analysis based upon the χ Lup spectral data was published (Wahlgren, Adelman, & Robinson 1994). A similar analysis for HR 7775 is currently being conducted by Wahlgren.

6.2 The Chi Lupi Atlas

Since considerable GTO time was devoted to observations of χ Lup, the GHRS GTO team will publish an atlas of all small aperture GHRS observations of this star (Brandt et al., in preparation). Proffitt played a key role in assembling the data and procedures that will allow for the production of the atlas in a form that will maximize its utility for the astronomical community. A poster introducing the atlas (Proffitt et al. 1997) was presented at the GHRS Science Symposium. A draft version of the atlas that included all high signal-to-noise ratio echelle GHRS observations of χ Lup was assembled. Completion of the final version awaits updates to available line lists.

6.3 Non-LTE and Radiative Force Calculations

Proffitt modified the non-LTE model atmosphere code TLUSTY so that it includes the calculation of radiative forces on individual ions that are treated in non-LTE. Brage and Proffitt also prepared extensive model atoms for Hg I, II, and III, and Tl II, III, and IV. These model ions were used, together with a model atmosphere of χ Lup, to study the nature of the heavy element anomalies observed in this star.

Initial work concentrated on thallium. A zero-velocity equilibrium profile, where the radiative force levitating thallium roughly balances the downward gravitation force, was derived for thallium in the atmosphere. It was demonstrated that this abundance profile was inconsistent with the observed strength of the Tl II line at 1909 Å. This suggested that processes other than simple diffusive equilibrium in the presence of radiative levitation have a strong effect on the abundance distribution of thallium. The results of these calculations were presented at the *Model Atmospheres and Spectrum Synthesis Workshop* that was held in Vienna, Austria during July 1995 (Proffitt et al. 1995), and were also published as part of Leckrone et al. (1996).

Work on mercury in χ Lup is still ongoing. Non-LTE effects alone are unable to reproduce the large excess equivalent width observed in the 1738.5 Å Hg III line (Proffitt et al. 1995). Matching this line with a standard synthetic spectrum that assumes a chemically homogeneous atmosphere requires a mercury abundance 1.3 dex higher than that determined from Hg II lines. While non-LTE effects do lead to overpopulation (relative to LTE populations) of Hg III levels, the line in question is formed at a relatively large optical depth, where the high collision rate prevents extreme departures from LTE. This suggests a vertically stratified Hg/H profile. If the bulk of the mercury is located at small optical depths, a large Hg III / Hg II ratio would naturally be produced.

However, the radiative force calculations on mercury seem to suggest a rather different picture. As is the case for thallium, the calculated radiative forces on mercury are inadequate to support the observed photospheric abundance. The latest calculations demonstrate that the radiative forces are a factor of ten to one hundred too small to support the observed abundance. One possibility is that the observed abundance can be supported below the observed photosphere, and then mixed upwards by residual convection or other hydrodynamic instabilities. However, this would then leave no clear explanation for the strong Hg III line, as such mixing would erase any vertical stratification of chemical abundances. Work is continuing to evaluate the extent to which other mechanisms (such as magnetic fields, mass loss, or light induced drift) might increase the amount of mercury which can be supported in the atmosphere.

In addition to the modifications made to TLUSTY, Proffitt also modified the companion synthetic-spectra code SYNSPEC to allow it to independently calculate radiative forces on individual ions. While some diffusion calculations that require comparison of transition rates are still more easily done within TLUSTY, one advantage of using the synthetic-spectra code instead for radiative force calculations is that it is easier to include the effects of line blends between different elements. Another advantage is that LTE radiative force calculations can be done simultaneously for all lines and elements included in the input line list. Such calculations have been performed for χ Lup with calculating the radiative transfer at 1.5 million frequency points and including over 500,000 line transitions. Such comprehensive calculations allow the radiative forces on many different elements to be directly compared. This is especially useful in the context of χ Lup where the "Pathfinder Project" has yielded abundance measures for 47 different elements to date.

6.4 Atomic Physics

Much of the above work would be impossible without adequate atomic data. Some data, such as highly accurate wavelengths, are best obtained via laboratory measurements. Other data, such as f-values, relative isotope shifts, and hyperfine structure are often more practical to obtain from theoretical calculations than from experimental work, especially when needed for a large number of levels or transitions. Brage was already performing such calculations in support of this project as an NRC postdoc, prior to joining CSC, where he continued this work.

Brage, Proffitt, and Wahlgren worked on determining oscillator strengths and hyperfine structure parameters for heavy ions. These parameters are necessary for synthesizing stellar spectra and producing non-LTE models for stellar atmospheres. The method involves three levels of accuracy. For a few observed transitions, a very accurate (to a few percent) and focused Multiconfiguration Dirac-Fock (MCDF) restricted active space method is used. A moderately accurate (to 5–20%) MCDF cross-optimization calculation is then performed for a number of important low-excitation transitions. Finally, a semi-empirical calculation (SE) treats a large model ion, including thousands of transitions.

Brage and Wahlgren used this method to compute oscillator strengths for different ionization stages of the triad of elements, strontium, yttrium, and zirconium. This project is of particular interest since adjacent elements can be used as an indicator of nuclear processes which may be responsible for overabundances. Brage demonstrated the importance of including an accurate treatment of core polarization in these ions, showing a decrease in oscillator strength of 20–35% as compared to earlier calculations. The results imply an overabundance of strontium and yttrium, and an ionization imbalance of 0.50 dex from comparison of Y II and Y III abundances.

Wahlgren and Brage (Wahlgren et al. 1997) also used the Cowan code to calculate oscillator strengths for line transitions of the ions W II and Os II. Lines from these ions have been either identified (Os II) or searched for (W II) in the GHRS spectrum of χ Lup. The abundances of these elements in the atmosphere of χ Lup do not appear to be enhanced much beyond the solar system values and serve to highlight the incredible abundance enhancements for the adjacent elements Pt, Au, Hg, and Tl.

Brage and Proffitt worked on a project to produce oscillator strengths for heavy ions, including Hg I, Hg II, Hg III, Tl II, Tl III, and Bi II. Since the nuclear charge is around 80 for the systems of interest, fully relativistic methods must be used. Emphasis was placed on accuracy and an estimate of uncertainties. Transitions between lower levels were treated with *ab-initio* MCDF methods, for which a new algorithm for systematic calculations was developed. The results were then augmented with a large number of semi-empirical results for transitions between highly excited states. In particular, important differences between Brage's fully relativistic calculations, and earlier quasi-relativistic ones for the Bi II atom, showed that this system is an interesting testing ground for atomic physics.

Brage started a project to collect oscillator strengths for Pt II. Matching results from large-scale calculations with experimental energy levels will produce a useful line list for spectral synthesis.

Brage made an effort to present and distribute atomic data by creating a home page, in collaboration with some other atomic theory groups around the world. This home page, of the Systematic, Accurate, Multiconfiguration (SAM) calculations project, can be found at `http://aniara.gsfc.nasa.gov/sam/sam.html`.

6.5 Plasma Diagnostics

Brage completed a study on the use of hyperfine induced transitions $nsnp\ ^3P^o - ns^2\ ^1S^o$ in beryllium- and magnesium-like ions, as diagnostics of low-density plasmas. For this project Brage performed systematic, large-scale calculations to compute probabilities for these type of transitions, including uncertainty estimates. The results show that these transitions can probe a new, lower range of densities than the standard UV diagnostics in these ions. Brage and collaborators also showed that these lines can be of interest as potential diagnostics of isotope abundance ratios, since they only occur in ions with non-zero nuclear spin. The work included new and improved atomic calculations, developed scaling laws for interpolation to new ions, and suggested observable candidates. For planetary nebulae they are the C III and N IV systems, while promising solar coronal candidates are Na VII, Mg IX, Al X, K VIII, K XVI, Cr XIII, Fe XV, Fe XXIII, Ni XVII, and Ni XXV.

6.6 Hyperfine-Induced Transitions

Brage extended a previous project on hyperfine-induced transitions to treat magnesium-like ions (Al II, Si III, Fe XV, ...). New candidates of astrophysical importance were pointed out.

6.7 Intercombination Lines

Brage and J. Fleming (Queens University, Belfast) worked on a long term project involving intercombination lines of carbon- and silicon-like ions (N II, O III, P II, S III). These are often important density diagnostics in low-density plasmas. Using recent GHRS spectra of RR Tel, they investigated the accuracy of different atomic models. The computed lifetimes were found to be in excellent agreement with laboratory experiments, while some ambiguities remains for the branching ratios.

7 Interstellar Medium – Subtask 7

Work under this subtask was performed by Bruhweiler in collaboration with Smith on a variety of observational and theoretical topics related to the interstellar medium (ISM). It expanded to include projects involving UV and high-energy observations of extragalactic objects.

7.1 Alpha Gruis

Bruhweiler worked on several studies which investigated the interstellar gas toward the nearby star α Gruis. One described the ionization structure, while the other examined the velocity structure seen in the Ech-B data for the Si II, Mg I, Mg II, and Fe II lines. Comparisons with detailed theoretical models showed that the observed C IV column density might not be in conflict with conductive interface predictions if the interior of the Loop I remnant is at a temperature hotter than the 1×10^6 K used in most conductive interface models, including those of Cheng & Bruhweiler (1990, ApJ, 364, 573). The observed diffuse X-ray emission seems to imply temperatures near 3×10^6 K, a value hotter than that for other directions outside of the Loop I complex. Yet, the conductive interface models cannot explain the large Si III column density seen toward α Gru. The conductive model interpretation would still be valid, however, if photoionization from the early B stars in the Sco-Cen region are the physical cause of the Si III absorption features.

The interstellar line profiles acquired using the Ech-B mode of the GHRS clearly showed complicated profiles in all of the ionic species observed for the line of sight toward α Gru. Although this structure could be interpreted as multiple clouds for this very short line of sight (26 pc), the more likely interpretation is that this decidedly non-Gaussian velocity field occurs because of the presence of shocks in the Local Cloud. Such a field is to be expected if the Local Cloud is a cloud fragment of the shell comprising the Loop I supernova remnant. Detailed profile fitting and deconvolution of the Ech-B interstellar line data showed that the narrow velocity component toward α Gru cannot have a temperature above 5000 K. This was seen most dramatically in the Ech-B data for Mg I, which penetrates the Local Cloud core. A much broader component at more positive velocities was also seen. It is presumed to be formed by the warm envelope of the Local Cloud.

7.2 Zeta Ophiuchi

Bruhweiler was involved in the analysis of interstellar absorption-line data acquired by the GHRS for the line of sight toward ζ Ophiuchi in collaboration with Smith and Ebbets. These spectra show molecular CO and OH, as well as ionic species of C I and S I. The focus of the work was to use these lines to probe the cool regions and determine pressures and temperatures of the molecular clouds along the line of sight to this star.

Bruhweiler first applied the refined tomographic techniques developed by Lyu, Bruhweiler & Smith (1995) to remove the fixed pattern noise from a large fraction of the existing ζ Oph data. He then fit the observed profiles with multiple Gaussians to get preliminary estimates for the column density and followed this with proper Voigt-profile modeling. The derived column densities of C I, C I*, and C II** were used to provide reliable characteristic pressures for the interiors of the diffuse molecular clouds along the line of sight toward ζ Oph. Bruhweiler then adapted a radiative transfer code previously used to calculate level populations in CO to calculate the populations in the three J-levels of the ground configuration of neutral C (cf. Lyu, Smith & Bruhweiler 1994). This code is an improvement over that used by Shay and Jenkins in that it has better collision cross-sections and includes a better representation of the ambient radiation field seen by the carbon in interstellar clouds. The results for C were then used in conjunction with calculations of the rotational levels of CO in order to separate the effects of density and temperature from the overall pressure ($p/k = nT$), which is near 3000 K cm^{-3}. It was found that the temperature and density derived from the CO and C I profiles are dependent upon the fraction of para- and ortho-molecular H_2 present, since these two forms of H_2 have different excitation cross-sections for CO and C I. The relative fraction of these molecules should depend upon the temperature (kT) of the gas. Further work is necessary before the final results can be presented.

7.3 White Dwarfs

Bruhweiler and Smith used the *EUVE* to study nearby white dwarfs. This was part of a program to map out the morphology of the local interstellar medium, determine the He and H ionization ration in this gas, and determine the intrinsic stellar features in white dwarf spectra. The results of this study were then integrated with the GHRS program results, especially the observations of α Gru. Previously, a method using tomographic techniques had been successfully applied to GHRS data to achieve S/N greater than 200. It was originally proposed by Bruhweiler to use a similar technique on *EUVE* data in an attempt to remove the fixed-pattern noise inherent in the three microchannel plate detectors. However, after tests, it was found that the *EUVE* could not reposition the target on the detector accurately enough to utilize the tomographic methods. Consequently, a methodology of smearing out the fixed-pattern noise was utilized, with data collected at 15 different reference points. This effectively randomized the fixed-pattern noise such that it mimicked Poisson statistics. This technique was used on several nearby hot white dwarfs.

Analysis of Ech-B data for Mg II for the line of sight to to the white dwarf G191-B2B shows complex features which can be modeled by two Gaussian components. This star is in the opposite direction from α Gru and intersects just the Local Cloud skin. The total H I column density in this direction is $\sim 1 \times 10^{18}$ cm^{-2}.

7.4 Starburst Knots in NGC 4449

Observations of six starburst knots were obtained using the *IUE* in January 1994. All the data are of exceptional quality and were used to derive ages, luminosities of the knots, and some indication of the star formation history in that galaxy. This study represents an outgrowth of a UV rocket experiment in which the strong UV fluxes of these starbursts were found.

Bruhweiler worked with M. Neubig (CUA) to construct a spectral library which included stars from the Galaxy and the Magellanic Clouds. This library was designed to serve as a data base for a population synthesis code to reproduce UV spectra of starburst knots obtained both with *HST* and *IUE*. The library consisted of O and B star ultraviolet data collected with the *IUE*. This effort began in earnest after assessment of *IUE* spectra and reclassification of the Magellanic stars to conform better with their observed UV characteristics.

7.5 The BL Lac Object Markarian 421

Observations of Markarian 421 using *CGRO*, *ASCA*, *EUVE*, *IUE*, and ground-based observatories at optical, IR, radio, and gamma-ray wavelengths were made during the period April 2–14, 1994. The monitoring represented an international effort to understand the physical processes that are responsible for the unusually strong gamma-ray flux observed at 10^{12} eV by the ground-based Whipple Observatory. The *IUE* and *EUVE* observations indicated approximately 10% variations over this time. The *EUVE* Deep Survey data showed the same trend in temporal variation as seen in the *IUE* data, but the magnitude of the variation was much more pronounced. The EUV flux of Mkn 421 showed a factor of two increase over a ten-day period. The corresponding gamma-ray EGRET observations during the same October 3–12 time frame showed no noticeable change. This suggests that the gamma-ray events may be uncorrelated with the UV and EUV.

Mkn 421 was reobserved by *IUE*, *ASCA*, *CGRO*, and the ground-based Cerenkov array at the Whipple Observatory on May 15-16. During this time, the Whipple Observatory detected a gamma-ray "flare" indicating gamma-rays of 10^{12} eV. Mkn 421 is the only extragalactic object ever detected to emit photons at these high energies. Moreover, this is the only time that Mkn 421 has been detected over a wide range of energies coincident with such an event. The *IUE* fluxes were 15% above the high UV flux levels of April, while *ASCA* showed a factor of two increase at 2–15 KeV. During the outburst the shape of the UV continuum was an extraordinarily flat power law which seemed to be slightly less negative for higher UV flux levels. Also, while the EGRET ($E > 100$ MeV) fluxes showed some enhancement, they were far below the increases at 10^{12} eV.

7.6 Theoretical Studies

Bruhweiler and collaborators developed time-dependent ionization calculations of the local ISM (LISM). This code represents a modification of a code written by C.- H. Lyu, as part of his Ph. D. thesis at CUA. This code calculates the ionization versus time in the ISM resulting from a UV-flash of a supernova (SN) explosion. It accurately treats the brief ionizing period (less than a day locally), as well as the long recombination phase (107 years) afterwards. Preliminary results show that a "weak" SN-explosion like that of SN 1987a would not be sufficient to significantly ionize the H or He in an expanding interstellar bubble complex (50–100 pc radius) around the stellar progenitor. This situation is far different than the very nearby ($\sim$ 1 pc) circumstellar matter around SN 1987a where extreme ionization is seen. If the luminosity is increased by 15–30, typical of what is deduced for other SN, then correspondingly higher ionization is found. Although more detailed calculations need to be performed, it appears that such an event will not lead to high ionizations over a large volume of the LISM. The results from this study have important implications in explaining the observed He II/He I $\sim 0.2 - 0.3$ ionization in the LISM.

In steps to check the developed algorithms used in the code, comparisons were made with numerical integration algorithms in the MAPLE software package using the Pentium computer at GSFC and a VAX machine at CUA. Initially, differences of 20–30% were found in integrations from MAPLE and the code run on a CUA VAX machine. The inconsistencies were traced to an error in the commercial version of the MAPLE package and not the Pentium processor. After performing these tests, further modeling of the LISM was initiated.

After testing of the time-dependent ionization code, preliminary calculations were made to determine what effect a strong shock and a UV-flash produced by a supernova would have on the deduced and observed ionization of hydrogen and helium in the local ISM. Such theoretical results have become crucial since recent *EUVE* observations have found that the He-ionizing radiation from the surrounding hot substrate is much lower than previous predictions have indicated. At the same time, the ionization of both hydrogen and helium are quite large. Acceptable fits were obtained with the models with reasonable age estimates for SN-events.

8 STIS Operations Support – Subtask 9

Activities under this subtask involved the development of the Space Telescope Imaging Spectrograph (STIS), a second-generation science instrument replacement for the GHRS and FOS, to be installed into *HST* in February 1997. Using their prior experience with GHRS and *HST* operations, Kraemer and Younger supported the STIS IDT in developing and testing the STIS flight software and its integration into the *HST* ground system. They worked with Ball AeroSpace, STScI, and GSFC personnel to develop and document the following items: STIS operational requirements and procedures, the ground system changes necessary for STIS operations, STIS proposal instructions, and the schedule for implementing the ground system changes. Ake, Crenshaw, and Robinson also assisted in preparations for the *HST* second servicing mission SMOV period, where initial in-orbit instrument calibrations and characterizations will be performed.

8.1 Management and Schedule Support

Because of the availability of three detectors, the use of eight different mechanisms, and the employment of several different target acquisition capabilities, STIS has a large number of different observing modes and options. This complexity, while highly beneficial for the variety of astronomical investigations allowed, presented a developmental challenge. The schedule for ground system and operations development was extremely tight. In fact, the STScI determined it would not be able to implement all STIS functions prior to launch. To set priorities and evaluate possible compromises, Kraemer, J. Grady (GSFC), and B. Woodgate (GSFC) met with STScI personnel in April 1995 to discuss a schedule proposed by the STScI for instrument commanding and ground system development. They reviewed a three-phase implementation plan and assessed the order in which various STIS capabilities would be available for in-orbit use. Throughout the instrument design, integration and test period, the STIS IDT, with Kraemer as representative, met with the STScI to track this schedule. This included a major revision to the plan during the summer of 1995 because of changes in the implementation of the STIS embedded flight software.

Kraemer also served as a representative of the IDT to GSFC and Ball for operations development. At a meeting of the New Generation Instruments Operations Working Group (NGIOWG) in February 1994, he presented the status of STIS operations and software development and the current schedule for flight software design, coding, and testing. Also, Kraemer had worked with J. Geiger (GSFC/Code 441) to assess the status of issues and actions that resulted from the STIS flight software requirements, and these requirements were presented at the NGIOWG meeting. Kraemer, Grady, and Woodgate attended the Continuous Process Improvement training classes in February and March

1994. As part of *HST*'s new management focus, the purpose of this training was to improve the process of implementing *HST* operations for the 1997 servicing mission. Kraemer aided Ball in the restructuring of the STIS Operations and Software Integrated Product Team (IPT), and assisted the new IPT leader, H. Garner, in creating level IV development schedules. He also supported the effort by GSFC/Code 441 to increase the STIS flight software (FSW) test staff by two people. In June 1995, Kraemer arranged for Younger to relocate to Ball to work with Garner. From May 1995 through September 1996, Kraemer tracked operations development and deliverables to the STScI from Ball and the IDT. He also provided management insight to GSFC of the FSW development effort at Ball.

Kraemer assisted Woodgate and R. Kimble (GSFC) in reviewing STIS operations and data throughput requirements for B. Kirkham (TRW) and R. Kutina (STScI), who were designing a reference mission study to assess the effect of the three high data-volume instruments, STIS, NICMOS, and WFPC2, on the entire *HST* system.

8.2 Flight Software Development

Kraemer assisted the IDT in the development of the requirements for the embedded STIS FSW, which operates out of the microprocessors within the STIS instrument. These microprocessors are considerably more powerful in terms of their computing speed and memory compared with the microprocessors associated with the first generation *HST* instruments. Consequently, the FSW development and its testing and integration with the *HST* ground system presented considerable demands on everyone involved in this effort.

8.2.1 Algorithm Development

Kraemer developed and tested algorithms for use within the STIS embedded flight software. The work included the documentation of these algorithms in the FSW requirements documents.

Kraemer and Kimble developed the FSW requirements for onboard target acquisition. This process includes not only finding the location of an external target in an aperture, but also determining the internal optical alignment with respect to the detectors. Kraemer, V. Krueger (GSFC), and I. Becker (Ball) developed a method for onboard image processing during the acquisition sequence. In June 1993, they had completed the preliminary design of the FSW process for locating a target within an image. After Kraemer and Kimble presented the details of onboard target-acquisition capabilities to the STScI in March 1994, there was agreement to remove onboard limb-fitting as part of the acquisition of extended solar system objects. Kraemer directed Lindler (ACC) to modify a threshold centroid routine used as part of the acquisition of planetary satellites. The software was demonstrated for the IDT in April 1994, and a separate demonstration was conducted at the STScI, to validate the algorithm. In May 1994, Kraemer and Kimble devised a cheaper and more efficient method of aperture location, taking advantage of the better than expected accuracy of the Mode Select and

Slit Wheel mechanisms. This method also improved the accuracy of locating the target. They instructed Ball to implement this improved technique.

Kraemer, with D. Rose and J. Coberly (Ball), developed the FSW requirements for protection of the MAMA detectors from over-illumination. This included the algorithm used in the MAMA Interface Electronics Processor to check MAMA images for local rate-limit violations. As a result of changes to the local rate limits imposed by the Ball MAMA engineers, Kraemer reworked the algorithm. In April 1996, Kraemer held meetings with Ball, GSFC/Code 680, and STScI personnel to discuss changes to the MAMA detector local illumination limits. He reviewed results of simulations run by Lindler and P. Plait (ACC) of the local rate-limit protection performance, and from these results, defined the onboard limits for the software.

8.2.2 Tests

Kraemer and Younger participated in the development of test facilities and the creation and execution of STIS tests in the phase prior to actual instrument testing. Unlike the first-generation instruments, where commanding was tested in an off-line system not used in-orbit, the second-generation instruments were to be tested in the Science Instrument Test System (SITS), which was to simulate closely the *HST* ground system. Because the command procedures and the associated data base inputs then would not have to be translated and revalidated in the *HST* ground system, the use of SITS would reduce costs and command development time.

Kraemer supported the testing, delivery, and integration of the STIS SITS components developed by IBM/Loral. He worked with Ball, GSFC/Code 442, and Loral to facilitate the installation of SITS, including the installation and testing of the SITS version of the NSSC-1 applications processors. Kraemer attended the SITS pre-ship functional test conducted on June 6, 1995 at Loral/Gaithersburg.

During the FSW development phase from March 1995 through June 1996, Kraemer monitored and assisted in the formal testing of FSW components. In June 1995, he met with Garner, Rose, and the FSW test team to review the details and requirements for tests. As a result of this meeting, Kraemer and Rose revised the near-term FSW development schedule to include hardware and software test milestones. Kraemer worked with Garner and Rose to determine software and operations support of the August 1995 Main Electronics Box test. In July 1995, he helped Ball to define the requirements for the software/hardware interface test with the STIS MAMA Electronics Memory Unit (EMU). He then wrote an outline of a test procedure for the Ball FSW test group. In early August 1995, Kraemer visited Ball to monitor the dry run of the MAMA detector EMU test, and returned in September for the actual test run. Kraemer also reviewed and redlined the STIS target acquisition component test.

In support of the STScI operations planning group, Kraemer coordinated the schedule for the pre-integration testing of STIS during the fall of 1995 and spring of 1996. He reviewed procedures for the first end-to-end functional test and met with D. Hood and J. Thorngren (Ball) to define requirements and the schedule for the functional and software baseline tests. Kraemer also worked with A. Rankin (Lockheed/MOSES) and Younger to discuss macro timing tests. Younger developed stored command sequences for the STIS system functional test and tested these on the flight software test bench. Also, in support of deliverables required by the STScI, Younger developed stored commanding used for regression and timing tests for all the STIS macros. Younger documented the results of these tests in the Command Block and Macro Descriptions for STIS document, DM-05. Through March of 1996, Kraemer made several subsequent trips to Ball to work the details of functional testing with Hood and Thorngren.

8.3 Ground System Development

Kraemer developed procedures for the efficient and safe operation of STIS within the requirements and constraints of the *HST* operating system.

8.3.1 Operations Procedure Development

Kraemer worked with Garner to define STIS operations procedures. These were included in an update of the STIS Operations Requirements Plan (Data Requirements Document, OP-01) – initially released in July 1994. From December 1993 to May 1996, the general operating requirements were developed during weekly telecons with Ball and Lockheed/MOSES personnel. In addition, with the assistance of Ball engineering subsystem leads, Kraemer and Garner compiled the list of operational constraints, restrictions, and limitations for the STIS sections in the *HST* Constraints and Restrictions Document (CARD) and the Operational Limitations Document (OLD). Several submissions of these requirements were made during the STIS development period; each submission was reviewed by GSFC and STScI operations teams.

Kraemer, with GSFC/LASP IDT members and Ball engineers, developed operational procedures for maintenance and protection of the MAMA detectors. These included bright-object protection and the recalibration of the Mode Select Mechanism (MSM) to ensure uniform MAMA microchannel plate use. Starting in January 1995, IDT members met on a semi-monthly basis with STScI operations and science support personnel to discuss these procedures. Kraemer made a final presentation of the procedures to a senior scientific panel, lead by D. Macchetto at STScI, in May 1996.

After consultation with Ball engineers, Kraemer wrote a procedure which recovers the MAMA detector after an autonomous high voltage turn-off. He presented a review of this procedure to STScI personnel in June 1996.

8.3.2 Instrument Commanding

Kraemer and Younger supported development and testing of the science instrument commanding system for STIS. This work included writing documentation describing the FSW commanding and how it is implemented through the *HST* ground system.

Kraemer developed commanding based on the macro commanding language developed by Becker for the embedded FSW. Kraemer and Rankin completed the design of the commanding structure and the accompanying requirements on the ground system and NSSC-1 FSW. Throughout the development period, Kraemer met with the

STIS team and STScI personnel to define the requirements for implementation of the commanding of all supported STIS capabilities.

Kraemer and M. Brumfield (GSFC/LASP) reviewed plans for calibration and commanding of the MSM. They agreed upon design requirements for retrieving encoder/resolver positions through the use of an onboard lookup table as a function of detector, grating, and wavelength selection. Kraemer worked with the IDT detector specialists, Ball, and the STScI to define the commanding requirements for MAMA bright-object protection. As part of the procedure design, Kraemer worked with the STScI on how to use the calibration insert mechanism as a shutter for the MAMA detectors.

Younger developed and updated the STIS DM-05 document which describes the commanding for the STIS Science instrument. This included command terms and definitions, flow charts, descriptions of macros and their timing, parameter definitions, and PSTOL descriptions. This document was used during the entire ground test period and during post-launch as the primary source of information on STIS commanding. Younger assisted R. Breyer (Ball) in bit validation reviews of command sequences for the STScI.

At the February 1994 IDT meeting, Kraemer and Kutina presented the current version of the STIS proposal instructions. At the suggestion of the team, Kraemer devised a new scheme for naming STIS modes and optical elements; this was later sent to the team for further review, and finally, to the STScI for implementation.

Kraemer attended the meeting of the Ground System Working Group in May 1995, and presented the status and plans for software memory management utilities developed by Ball for STIS and NICMOS.

8.3.3 Servicing Mission Observatory Verification

Kraemer, Ake, Robinson, Crenshaw, and Younger provided planning support for the second *HST* servicing mission and subsequent on-orbit verification of STIS performance.

Kraemer wrote the high-level SMOV requirements, which were submitted to GSFC/ Code 441 in February 1995. Kraemer also coordinated the writing of SMOV activity summaries by IDT members. The first set of these were presented to the *HST* Project at the SMOV meeting in September 1995. Kraemer presented the STIS SMOV plan to an *HST* Project review panel in April 1996, and responded to the panel's questions and recommendations in May 1996.

Kraemer assisted the IDT in the development of the servicing mission aliveness and functional tests. He supported Woodgate in presenting the STIS servicing mission functional test pass/fail criteria to the Servicing Mission Board in July 1996. Kraemer also supported simulated runs on the ground of the servicing mission tests.

Kraemer, Ake, Robinson, and Crenshaw prepared Phase 1 and Phase 2 proposals for SMOV. These included target acquisition tests, spectroscopic and camera mode image quality checks, spectroscopic thermal stability measurements, instrumental PSF measurements, detector flat-field stability measurements, relative slit transmission measurements, Doppler correction checks, and MAMA time-tag mode tests. They attended weekly meetings with the STScI on SMOV proposal development.

8.4 Instrument and Ground System Tests

Kraemer and Younger participated in the post-integration ground testing of STIS, including the testing and calibration of STIS in the thermal vacuum chamber at Ball during August and September 1996. They also assisted in tests of the ground system using simulators; these included the execution of tests that were to be run during the *HST* second servicing mission.

After instrument integration, Kraemer supported preparations at Ball during June 1996 for shipping STIS to GSFC for acoustic testing. Younger continued to work on operations development with Garner, Breyer, and Brewster at Ball and with Kraemer at GSFC. This work included developing, revising, and testing command sequences for the acoustics test in June and July 1996; he also helped support the acoustics testing at GSFC in early July. During the period the instrument was at GSFC, Kraemer was involved with off-line testing of the flight software and procedures. Kraemer, Kimble, Rose conducted tests of the bright-object protection FSW and the point-source target acquisition capability.

After the return of STIS to Ball in mid-July 1996, Younger commenced working on the development of stored commanding for thermal vacuum testing. Kraemer defined thermal vacuum test procedures to confirm slit wheel off-nominal positions for coronagraphic science. In July 1996, Kraemer returned to Ball for pre-environmental testing. Kraemer and Kimble re-executed the STIS bright-object protection test, and Kraemer, Kimble, and Rose conducted tests of MAMA charge distribution via offsetting of the STIS MSM.

In August 1996, STIS was inserted into the thermal vacuum chamber for an extended series of tests and calibration measurements. Younger participated in the vacuum alignment test as a SITS operator. He also developed, revised, reviewed, and tested SMS command sequences used during these tests, and he assisted in the development of a MAMA 1 high-voltage recovery and diagnostic data-collection command sequence. This command sequence was defined by Kraemer and Ball engineers after the MAMA 1 detector had been exposed to an abnormally large UV photon flux. A corresponding procedure was developed for the Band 2 MAMA, and that procedure was executed while STIS was at GSFC – post thermal vacuum – to provide a baseline measure of the MAMA 2 detector performance.

Upon completion of vacuum testing and calibration at Ball, STIS was returned to GSFC. Kraemer supported runs of the Servicing Mission Ground Test (SMGT) 24 Part 1 (Servicing Mission Aliveness and Functional Test) at the Vehicle Electrical System Test (VEST) facility and again at the *HST* Operations Control Center. He also supported the initial run of SMGT 24 Part 2 (STScI Generated Functional Test) at the VEST. Kraemer conducted tests of target acquisition capabilities with SITS, including slit illumination/location and cosmic-ray rejection, and he completed and delivered the test report from the MAMA 1 and MAMA 2 anomalous recovery tests. Younger supported STIS testing at GSFC, working as a SITS operator and developing, reviewing and monitoring the execution of some of the stored command SMSs. These included the MAMA 2 high voltage recovery SMS, the system functional SMS, and the mechanism mini-functional SMS for SMOV.

9 Infrared Data Base – Subtask 10

Pitts continued work on the Catalog of Infrared Observations (CIO) for D. Gezari (GSFC). From 1993–1996, many changes were made in the way the CIO was managed, maintained, and made available to the astronomical community. With the addition of more up-to-date software and hardware components, it became easier to add new information, make corrections, change the catalog's format, and import the data to other media. The CIO can now be accessed in the form of hardcopy, tape, or CD-ROM; via FTP; or interactively over the World Wide Web.

After publication of the third edition of the CIO in 1993, all data files, which had resided on an IBM mainframe, were ported to a desktop PC and converted to Paradox data base tables. As part of a true data base, it was possible to sort, query, and edit the CIO more efficiently. In addition, most routine data base maintenance was automated so that the process of adding and editing new material was much easier. Over 50 Paradox "scripts" were written which perform these functions, including creating new tables, merging and sorting data, running reports, reformatting tables, and making bulk corrections. Many of these scripts were incorporated into the Newdata Application, a self-contained procedure which is run within Paradox and which presents the user with various CIO-specific management options. Using this application, task members added over 900 articles comprising over 50,000 observations to the database.

The CIO grew to a size which was most conveniently distributed over the Internet. Shortly after printing the third edition, compressed files were made available via FTP. Soon it became apparent that the best way to advertise and distribute these files was through a World Wide Web page. The CIO Home Page was created and made public in October 1995. From the home page, Web users can find out about the purpose of the CIO and download all or part of the catalog. A link to the Strasbourg Observatory Vizier data base search engine allows the catalog to be queried over the Web. Some time was spent exploring the possibility of searching the CIO using locally-licensed Ingres data base software. That option is still in the beta phase. In addition, a collaboration was begun with the NASA Astrophysics Data Facility AMASE team to add the CIO to their object-oriented data base, also available over the World Wide Web.

In 1991 the CIO was included on the NASA Astronomical Data Center's (ADC) CD-ROM of Selected Astronomical Catalogs, Volume 1. At the request of the ADC, updated CIO files were created and made available for Volume 2, which is currently in preparation. Besides merging new data into the catalog, making corrections, and creating the properly formatted and sorted files, Pitts incorporated the latest version of the Equatorial Infrared Catalog into the CIO.

Two tasks were performed as supplements to management of the CIO. First, at the request of Gezari, sources near the Galactic Center were selected and their IRAS counterparts retrieved from the IPAC NASA Extragalactic Database. An IDL routine was written which plots source positions and brightnesses, and several plots were provided to him. Second, a commercial mapping program, Hypersky, was purchased. Since Hypersky accepts new input, a number of infrared catalogs are being prepared for inclusion in this program for future display purposes.

10 STIS Imagery – Subtask 11

Work under this subtask was to assist the STIS IDT in preparing for its GTO parallel observation program. The major part of the effort involved the development of a software tool for coordinated and pure parallel observation modes and providing assistance to the IDT with the selection of potential parallel targets.

Malumuth developed an IDL widget-based tool, named HST_PLANNER, to aid the STIS team in planning parallel observations using the WFPC2 or NICMOS when STIS is the primary instrument, as well as obtain parallels using STIS when WFPC2 or NICMOS is the primary instrument. He obtained an IDL program from O. Lupie (CSC/STScI) that plots an outline of the *HST* field of view, including the three FGS pickles and the WFPC2, FOC (with COSTAR), NICMOS, and STIS apertures using the current or expected V2/V3 coordinates for each instrument. Using this as a starting point, Malumuth wrote an IDL procedure to read a digital image in FITS or GEIS format and then display the image overlaid with the three FGS pickles and all instrument apertures. With this, a user can select the instrument for the primary observation from a pull-down menu and can either enter the coordinates of a target or select the target directly from the image using a cursor. The program then displays the *HST* field of view with the selected aperture centered on the selected coordinates. The user can use a slide bar to adjust the orientation angle, thereby examining whether an interesting object can be viewed with one of the other instruments. The program will display the day that the selected orientation is at the nominal roll for the spacecraft, the angle between the target and the sun on that day, and the visibility period for the target on that day. The user can also use a slider to select a given day and find the orientation angle, the sun angle, and the visibility period on that day. In addition, the user can search selected data bases and display the object locations on the image. Later improvements to the tool included the ability to calculate the amount of unocculted dark time available for a particular target on any given day and the time when a target will be in the continuous viewing zone. The program also draws an annulus at the radii of the selected parallel aperture centered on the prime aperture. This is very useful in seeing whether a given object can be observed in the NIC1 or NIC2 apertures in parallel with a STIS primary observation.

As an added benefit, Malumuth revised the HST_PLANNER tool to help STIS team members screen their proposed observations for objects which are too bright. This included the ability to get target magnitudes and colors from the University of Minnesota automated plate-scanning project. For sky survey plates which have been scanned, the user can get a table of objects and the E and O magnitudes of the objects by using the World Wide Web and the APS project home pages. This table can then be read into the HST_PLANNER tool. The tool calculates the V magnitudes and can display all of the objects, the objects brighter than $V = 20.5$ mag, or just the objects with magnitudes and colors that would violate the MAMA bright-target limit. The tool puts a circle around the selected objects. One can also obtain the magnitude of the selected object.

In working with his program, Malumuth discovered that the visibility period for a given target and orientation angle will vary over a two-year cycle, due to the *HST* 56-day orbital precession period. Thus, if the proposer has targets with specific orientation requirements, it might be useful to select the year in which to observe based upon the maximum target visibility.

Malumuth demonstrated his widget tool to the members of the NICMOS team during a joint STIS-NICMOS meeting held in October 1995 to discuss parallel observations, as well as during STIS team meetings in October 1995 and May 1996. Malumuth has also distributed a set of instructions for the widget planning tool to the STIS IDT members.

Malumuth has used this tool to help the STIS team to prepare for their program of parallel observations. This included such activities as helping Woodgate plan for his GTO program to observe Lyman alpha galaxies near the QSOs 2139–445 and 2138–444. He has also used the HST_PLANNER tool to examine a large number of the STIS team's proposed targets and has found a significant number with parallel targets in the STISPAR data bases. In particular, there are a number of IRAS point sources that are possible parallel targets for the NICMOS and WFPC2 which are connected with the observations of E. Jenkins (Princeton). Malumuth has produced several tables which list the exposure time at each pointing, the galactic latitude, whether a potential target exists for a pointed parallel, whether a parallel image with WFPC or WFPC2 has already been obtained in a field which can be obtained in parallel with STIS, and the orientation needed to observe these fields in parallel.

11 STIS Calibration – Subtask 12

Robinson participated in STIS prelaunch calibration activities during thermal vacuum testing. These tests were designed to validate STIS optical performance and check out instrument functions. Robinson worked on instrument calibration and characterization data to evaluate test results and prepare for later comparison with in-orbit measurements.

As part of the calibration effort, Robinson developed several IDL procedures for analyzing STIS images. The most important of these, called STIS_REDUCE, used predicted spectral-line positions to locate emission lines from a calibration-lamp exposure. The measured positions of the lines are then employed to obtain a least-squares fit relating the X and Y location to order number and wavelength. This fit locates the spectral orders on the image and also provides a wavelength calibration to the extracted spectra. This procedure allowed a completely automated extraction of spectra from a pair of STIS images, one calibration and the other science.

In April 1996, Robinson participated in the vacuum alignment tests conducted at

Ball Aerospace. During this time, the final tests on the band 2 MAMA were carried out and many of the initial CCD tests were conducted. The activities included ensuring that the optics were properly focused and aligned and determining the MSM positions required to get the proper wavelength and spatial position in each of the primary and backup observing modes. Other parts of the test included checking the calibration lamp brightness, testing out the CCD target acquisition algorithms, examining the gain and linearity of the CCDs, and checking for CCD fringing at long wavelengths. During this time Robinson helped check the data as it came in, did quick-look analysis for the various calibration tests, and produced shift reports which outlined the purpose of each exposure and summarized some of the real-time analysis being conducted at Ball.

Robinson used data obtained during the vacuum alignment tests to investigate the echelle blaze functions for the 1.3 and 2.3 echelle modes. This analysis resulted in reasonably good fits for mode 1.3. However, there were problems in the 2.3 analysis which were caused by the cosmetic quality of the detector. This was not a flight detector, so a repeat during the science calibration tests should provide much better results. Robinson also used the vacuum alignment data as well as data from observations taken at GSFC to study the effects of scattered light and worked on algorithms to remove this from the observations.

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